US Army Corps
of Engineers
Construction Engineering
Research Laboratory

USACERL Technical Report P-91/01, Vol II
November 1990
Building Technology Forecast and Evaluation

2

AD-A230 288

Building Technology Forecast and Evaluation (BTFE), Volume II:

Evaluation of Two Structural Systems

by
Thomas R. Napier
Carolyn E. Beer

This report develops a building technology forecast and evaluation (BTFE) cycle for identifying and analyzing new or innovative construction products/systems. The prototype cycle consists of four phases: forecast or identification of promising technologies, impact analysis (i.e., applicability to USACE), prioritization for further study, and detailed evaluation. Volume I of this report describes the BTFE cycle and demonstrates its use in performing the first three phases in a practice exercise. This application yielded two structural systems with potential advantage to the U.S. Army Corps of Engineers (USACE): tunnel forming systems and composite panelized systems.

Volume II describes the detailed evaluation of these two systems.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE
November 1990

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Building Technology Forecast and Evaluation (BTFE), Volume II: Evaluation of Two Structural Systems

5. FUNDING NUMBERS
PR AT41
TA SA
WU B59

6. AUTHOR(S)
Thomas R. Napier
Carolyn E. Beer

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Construction Engineering Research Laboratory (USACERL)
2902 Newmark Drive, PO Box 4005
Champaign, IL 61824-4005

8. PERFORMING ORGANIZATION REPORT NUMBER
TR P-91/01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Directorate of Military Programs
HQUSACE
ATTN: CEMP-EA
Washington, DC 20001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report develops a building technology forecast and evaluation (BTFE) cycle for identifying and analyzing new or innovative construction products/systems. The prototype cycle consists of four phases: forecast or identification of promising technologies, impact analysis (i.e., applicability to USACE), prioritization for further study, and detailed evaluation. Volume I of this report describes the BTFE cycle and demonstrates its use in performing the first three phases in a practice exercise. This application yielded two structural systems with potential advantage to the U.S. Army Corps of Engineers (USACE): tunnel forming systems and composite panelized systems.

Volume II describes the detailed evaluation of these two systems. To perform these analyses, it was necessary to further develop the evaluation procedure that Volume I explained in general terms. For the two systems identified, this process has to be adapted specifically to assess structural systems. General performance attributes related directly or indirectly to structural performance were identified. For each attribute, specific subattributes were selected to describe the structural performance more elaborately and explicitly. Design and construction criteria used to define these specific attributes were referenced to USACE and Department of Defense Specifications as well as to industry standards. The resulting evaluation process thus has an objective (quantitative) component that includes the tangible data related to design construction, experimentation, etc., and so on, and a subjective (qualitative) component that includes interview information (e.g., expert opinions) and published material. Volume II explains this evaluation procedure in detail.

14. SUBJECT TERMS
building technology forecast and evaluation
new technologies
buildings
construction
technology
evaluation

15. NUMBER OF PAGES
144

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

(A)

FOREWORD

This research was conducted for the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Project 4A162734AT41, "Military Facilities Engineering Technology"; Work Unit SA-B59, "Building Technology Forecast and Evaluation." The HQUSACE Technical Monitor was T. Kenney, CEMP-EA.

The work was performed by the Facility Systems Division (FS), U.S. Army Construction Engineering Research Laboratory (USACERL). Contributions to this study were made by Professor Mir Ali and Randall Anway, School of Architecture, University of Illinois at Urbana-Champaign. Annette Stumpf, USACERL-FS, also contributed to this work.

Dr. Michael J. O'Connor is Chief of USACERL-FS. COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

[illegible] words: Technology forecasting/methodology; State-of-the-art; Construction/building; Structural engineering; Army Corps of Engineers; Cost effectiveness; Resource management; Military applications; Structural analysis; Performance criteria; Quantitative/qualitative analysis; Test evaluation. [illegible]

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

CONTENTS

CONTENTS (Cont'd)

FIGURES

TABLES

BUILDING TECHNOLOGY FORECAST AND EVALUATION (BTFE), VOLUME II: EVALUATION OF TWO STRUCTURAL SYSTEMS

1 INTRODUCTION

Background

Many different innovative or new construction technologies being marketed today may represent cost-effective, expedient alternatives to traditional building types. These technologies are of growing interest to the U.S. Army Corps of Engineers (USACE), which is responsible for a $1.4 billion/year military construction program. As USACE attempts to provide the Army with quality facilities while facing increasingly lower budgets, it will need to consider adopting building products and systems that can result in (1) a lower cost for equal quality or (2) better quality at the same cost as conventional construction (and therefore an improved life cycle).

An obstacle to implementing new or innovative technologies has been the lack of proper guidance for selecting those most suitable to Military Construction, Army (MCA) and other military construction (MILCON) projects. Failure to choose appropriate systems based on comprehensive analyses can have catastrophic results, including structural failure. Therefore, any new or innovative technology must show potential for meeting the same requirements and specifications as conventional construction.

USACE needs a systematic approach for identifying and evaluating these alternative technologies. To be effective, this approach would need to apply to the large number and variety of building types prevalent in U.S. military construction. The procedures must reflect current professional practice, meet USACE requirements, and be applicable to the state of the art in building construction. In addition, the methodology must be generalized and flexible enough to incorporate new knowledge as it becomes available.

Information collected in a building technology forecast and evaluation (BTFE) process would be mutually beneficial to USACE and private industry. In addition to helping USACE select appropriate technologies, BTFE will identify areas of products or systems that could be improved, providing industry with valuable feedback. Information on these technologies also could be used to develop a statistical data base that would provide a useful tool for decision-makers in selecting new or innovative building technologies.

Objective

The objective of this study is to develop a systematic methodology for forecasting and evaluating building technologies. The specific objectives of Volume II are to expand the evaluation phase of the prototype BTFE cycle for examining structural systems and to use this approach to evaluate two systems. Volume I explains the BTFE cycle and describes a practice exercise of the first three phases in which the two systems were identified for further evaluation.

Approach

In Volume I of this report, a general BTFE cycle was proposed which consists of four phases: forecast or identification of promising technologies, impact analysis (i.e., applicability to USACE), prioritization for further study, and detailed evaluation. To evaluate the two technologies identified in the

practice exercise, the evaluation component of the cycle was developed from its very general focus into a set of guidelines specifically for assessing structural systems.

Several general performance attributes related directly or indirectly to structural performance characteristics were first identified. Then, for each attribute, specific subattributes were selected to describe the structural performance more elaborately and explicitly. Design and construction criteria related to these specific attributes were referenced to USACE, Department of Defense (DOD), and industry standards. This relationship was established to allow a comparison of required performance criteria with actual performance characteristics of a structural system. The resulting evaluation process contains an objective (quantitative) component that includes the tangible data related to design, construction, experimentation, and field investigation, and a subjective (qualitative) component that includes opinions of architects, engineers, contractors, manufacturers, and so on, as well as published material.

A rating sheet was developed for recording the engineering data corresponding to the objective rating and the empirical data corresponding to the subjective rating. The rating sheet relates this information to the attributes and facilitates a numerical determination or measurement of the performance characteristics for any structural system evaluated. Using input from several design professionals, attribute weighting factors were assigned. These factors reflect the relative importance of performance factors with respect to each other. The objective of the rating sheet is to derive a System General Rating (SGR) for a given structural system. The SGR indicates the technology's suitability for MCA projects.

This detailed evaluation procedure was used to examine two structural systems: a tunnel forming system and a composite panelized system.

Scope

This investigation concentrates on building technologies related to structural systems and major structural components. Materials and products associated with the components are not considered. Application of the proposed methodology is limited to two low-rise residential systems called the tunnel forming system and composite panelized system. A third product, called the Strickland System, is also investigated, but no detailed evaluation is conducted. Although the methodology has been developed for a particular type of evaluation (structural), it is essentially generic and is not necessarily project- or site-specific. Additional considerations may be required to apply this methodology to a specific project at a particular site. Finally, it should be emphasized that the procedures proposed in this report are intended to serve as a tool to provide consistent guidance for evaluators; it does not substitute for professional expertise in selecting building technologies.

Mode of Technology Transfer

It is expected that new/innovative technologies identified with the prototype BTFE cycle will be demonstrated during FY90 under the Technology Transfer Test Bed (T^3B) program. In addition, this methodology has been submitted to Headquarters, USACE, and accepted as a candidate for development as an industry standard under the Construction Productivity Improvement REsearch (CPAR) program; a private company has proposed to be a cosponsor. Three possible mechanisms are being considered for implementing the final product (1) establish a dedicated support center at a District office to serve all of USACE, (2) contract an external service that would be responsible to some USACE representative (e.g., the Corps of Engineers National Alternative Construction Technology Team [CENACT], or (3) use leveraging through CPAR to establish a private agency, and then subscribe to the BTFE service it provides.

2 FACTORS TO CONSIDER IN EVALUATING STRUCTURAL SYSTEMS

Identifying Structural Attributes and Characteristics

Virtually an endless variety of structural systems exists. A particular system derives its unique character from a combination of considerations. These considerations comprise the qualitative characteristic features or inherent behavioral properties of a structure and its components. Separately considered, such considerations characterize the major performance requirements of a structural system and its components, and can be called "attributes." All structural systems share the general attributes described below.

General Attributes of Structural Systems

The general attributes relevant to a structural system are:

- Structural functions, which represent the strength, stiffness, and stability characteristics at the service and ultimate load levels, and the compliance with code regulations.
- Structural form and scale, representing the elements' limitations, the production process, the need for special functions, and esthetics.
- Materials, defining the suitability of materials for building elements, limitations on spans of elements, and the nature of joining imposed by the material properties.
- Connectivity of elements, defining the nature of connections between articulated structural elements, bracing systems, and the method of supporting the structure.
- Constructibility, dealing with the ease of building the structure. These issues may include erection, material handling, quality assurance, labor, equipment, temporary supports, and speed of construction.
- Optimality, suggesting cost-effectiveness and least material consumption.
- Specific loading, or the loads or combinations of loads that the structure is expected to support.
- Architectural functions, defining the primary architectural provisions of the structure. These include, for example, enclosure, interior spatial definition, unobstructed interior space, and massing of the building.

These general attributes can be related to any specific building technology. From a structural performance viewpoint, the structural function attributes that correspond to the safety and serviceability of the structural system are most significant. The general attributes are expanded below to list the more specific, detailed requirements for adequate structural integrity and performance.

It should be noted that a building structure essentially goes through three basic stages during its life:

1. Design, including the conceptual design, planning, and detailed design.

2. Construction, beginning with groundbreaking and terminating when the building is completed in all respects including the finishes.

3. Occupancy, which is the service life of the building.

All attributes can be related in some way to these three stages. Figure 1 demonstrates how the various phases of the design process influence the structural performance. From the figure, it is clear that any human error or incongruence during the design stage may have serious repercussions on the structural performance, as explained in more detail below.

Specific Structural Performance Attributes

Detailed or specific attributes related to the structural safety and serviceability performance also can be related to each of the three stages comprising a building's useful life. Figures 2 through 4 summarize these attributes by life-cycle stage.

The specific attributes shown in Figure 2 define the various inherent qualitative, tangible characteristics that must be addressed during the design process. Any error or inadequacy in these attributes will in some way influence the structural system's performance during construction and occupancy. For example, if the specifications or drawings are incorrect or incomplete, the building performance will suffer at some point.

Figure 3 shows the attributes during the construction phase with specific attributes listed under the principal attributes. Structural safety and economy are the main attributes during construction. Fire safety also is critical. Some important specific attributes under structural safety are the load-carrying capacity, temporary structures used to support and brace the building under construction, the changing structure, material handling, and quality control. Loads and load combinations play a significant role in determining the structure of a building and are classified separately in Figure 5.

Figure 4 shows the attributes during the building's service life when it is occupied. Safety and serviceability are the two principal attributes shown.

Other Attributes

Other important attributes that may affect the performance of a structural system are habitability, durability, span length, and maintainability. Table 1 is a detailed list. Although some of these attributes are not directly or explicitly related to the building structure, they may implicitly affect the structural performance, and therefore are included in the list of attributes.

Influence of Other Building Systems

Good design practice requires integration of the structure into the whole physical system of the building. It is important to realize the major influences of other building systems on structural design decisions. Some structural systems often become popular because of their adaptability to the other building service systems.

Integration of the structure with the following building systems and subsystems is absolutely necessary:

- Architectural systems
- Heating, ventilation, and air-conditioning (HVAC) systems.
- Power
- Lighting
- Plumbing.

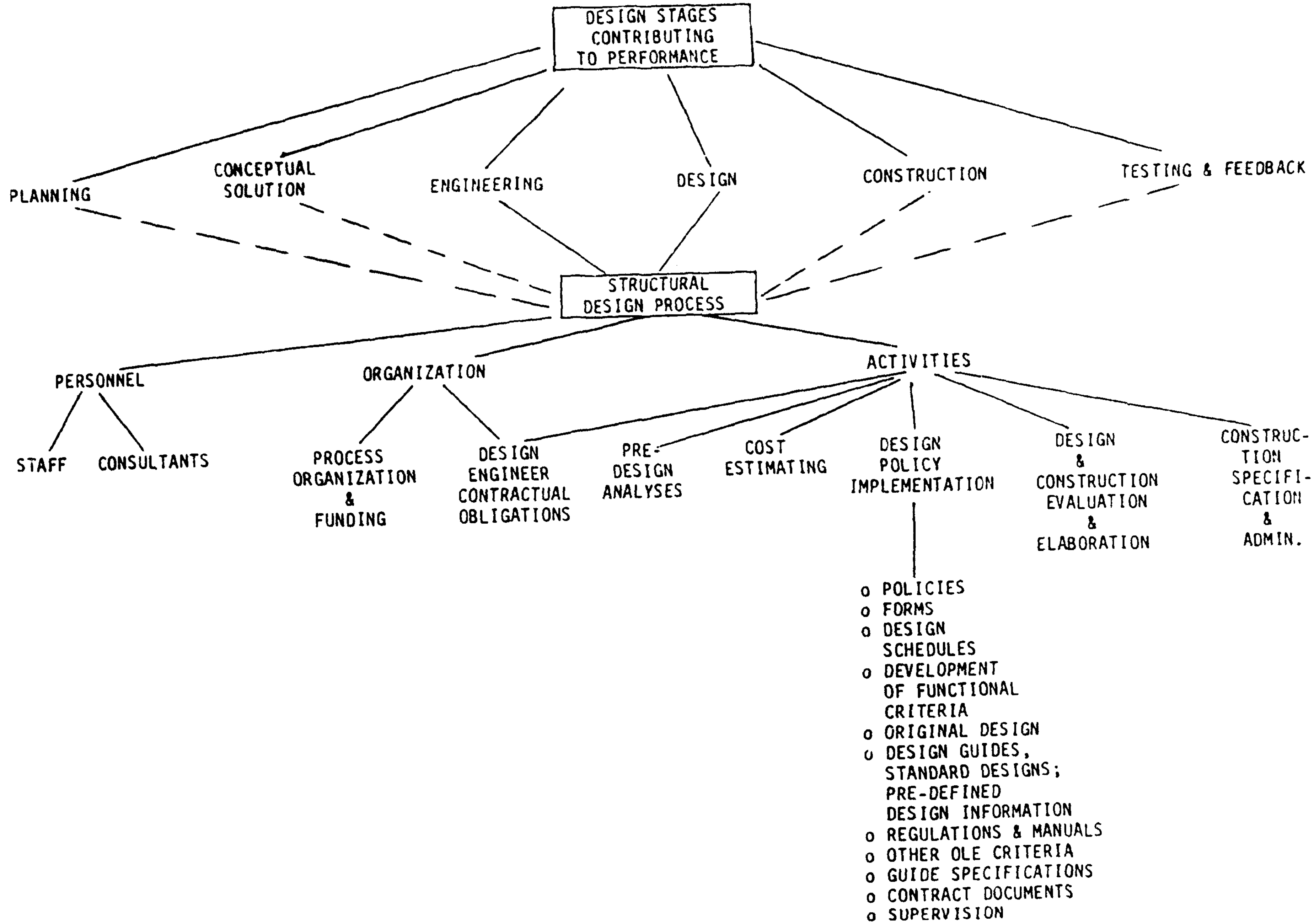


Figure 1. Relationship of design process to structural performance.

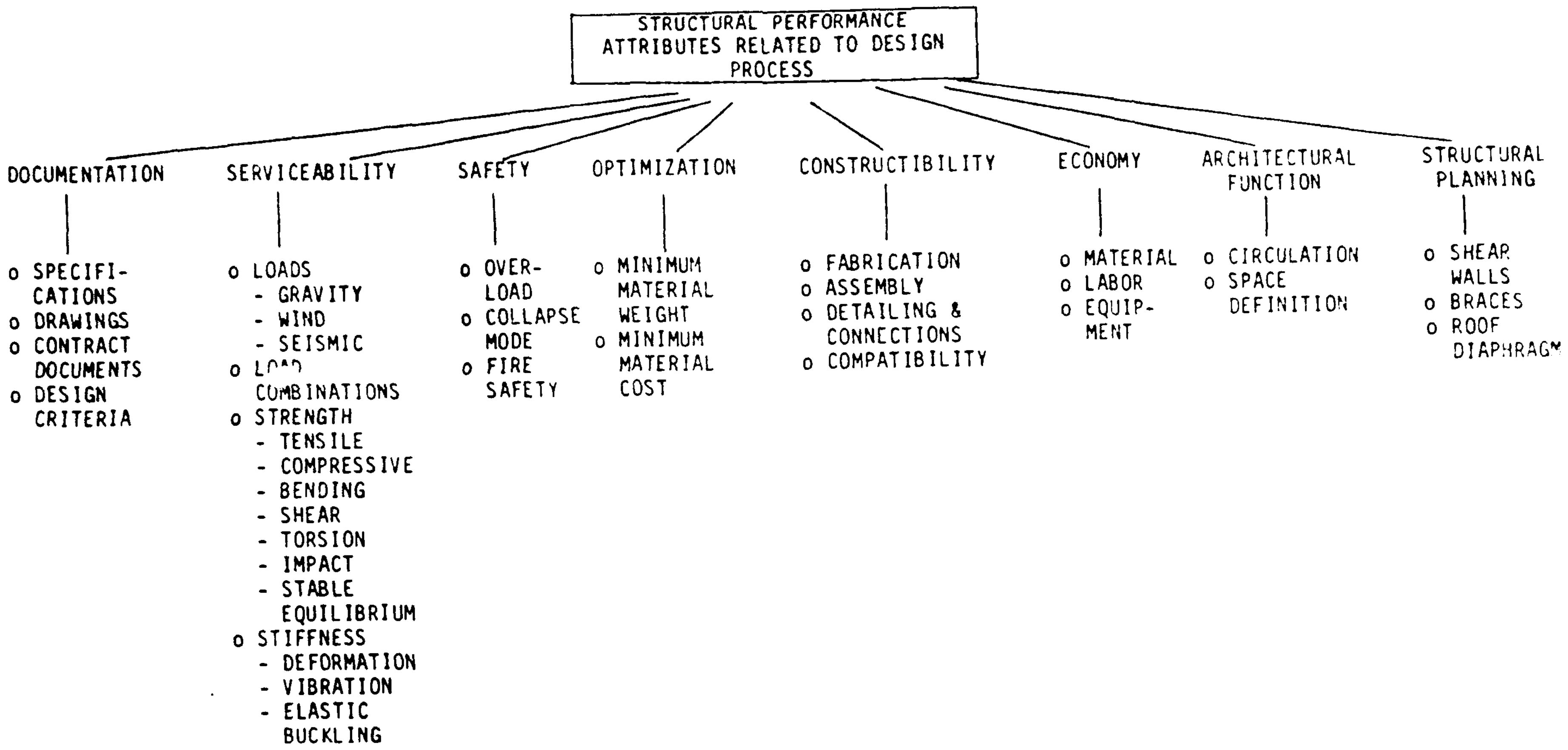


Figure 2. Structural attributes related to the design phase.

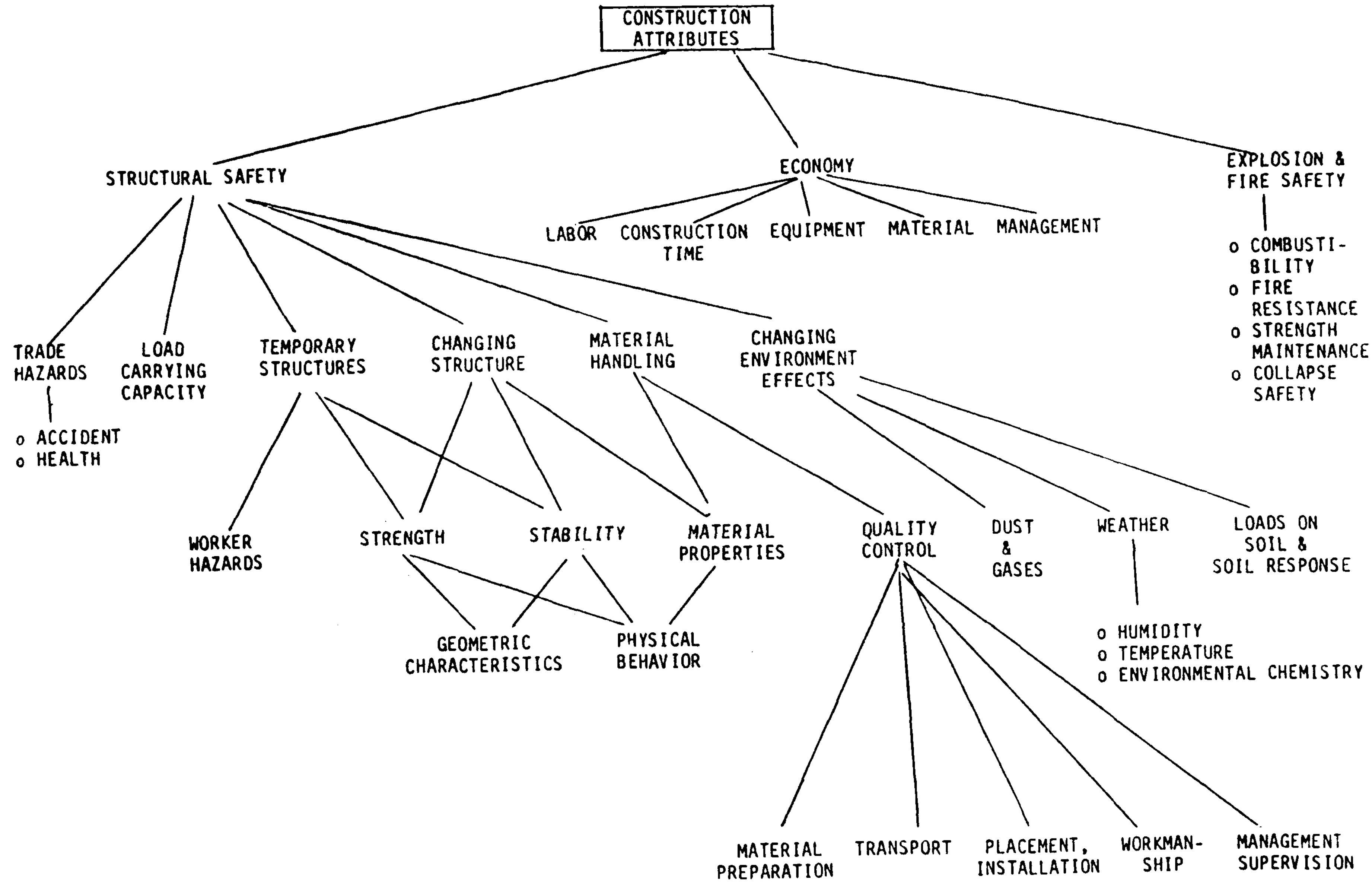


Figure 3. Structural attributes related to the construction phase.

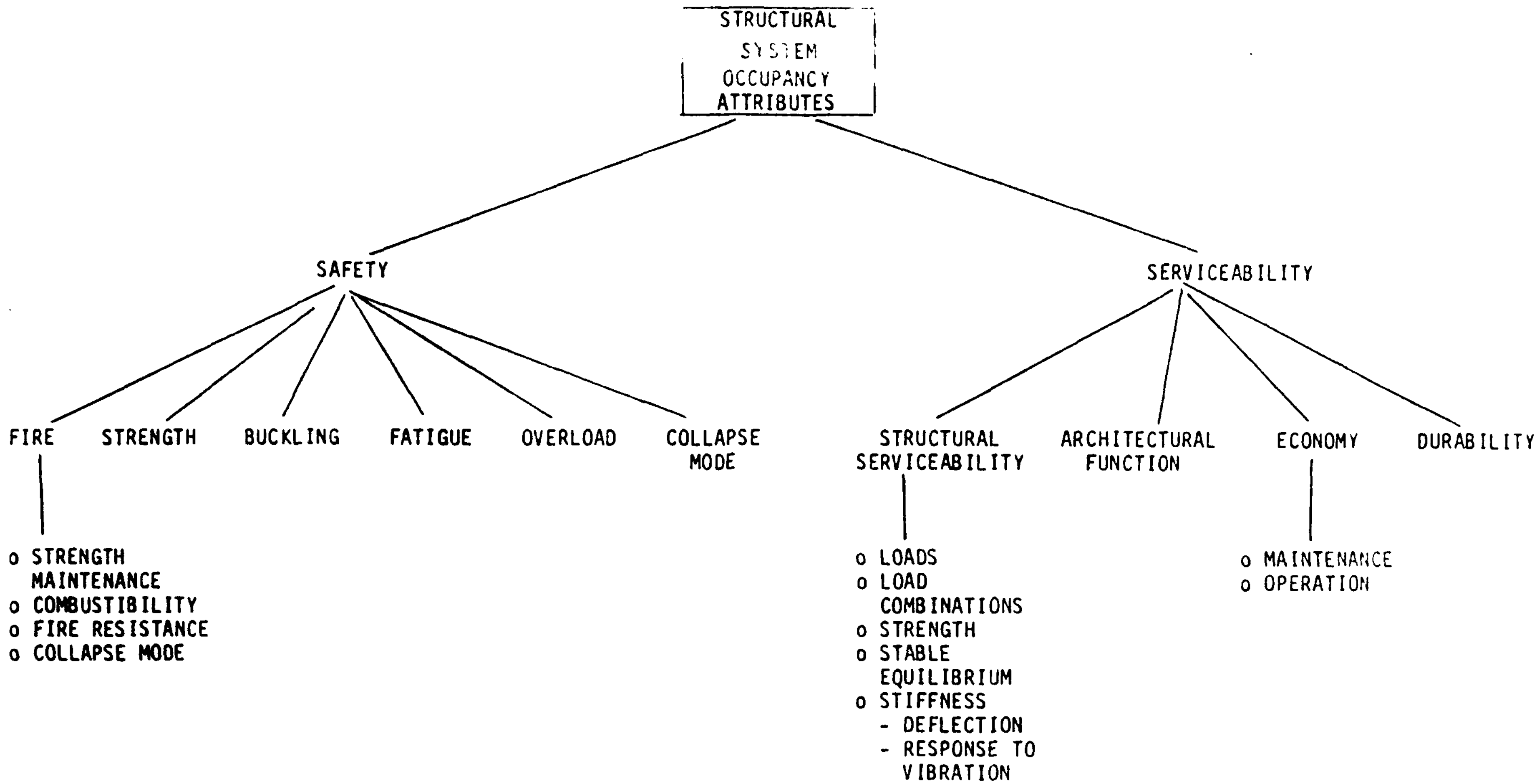


Figure 4. Structural attributes related to the occupancy phase.

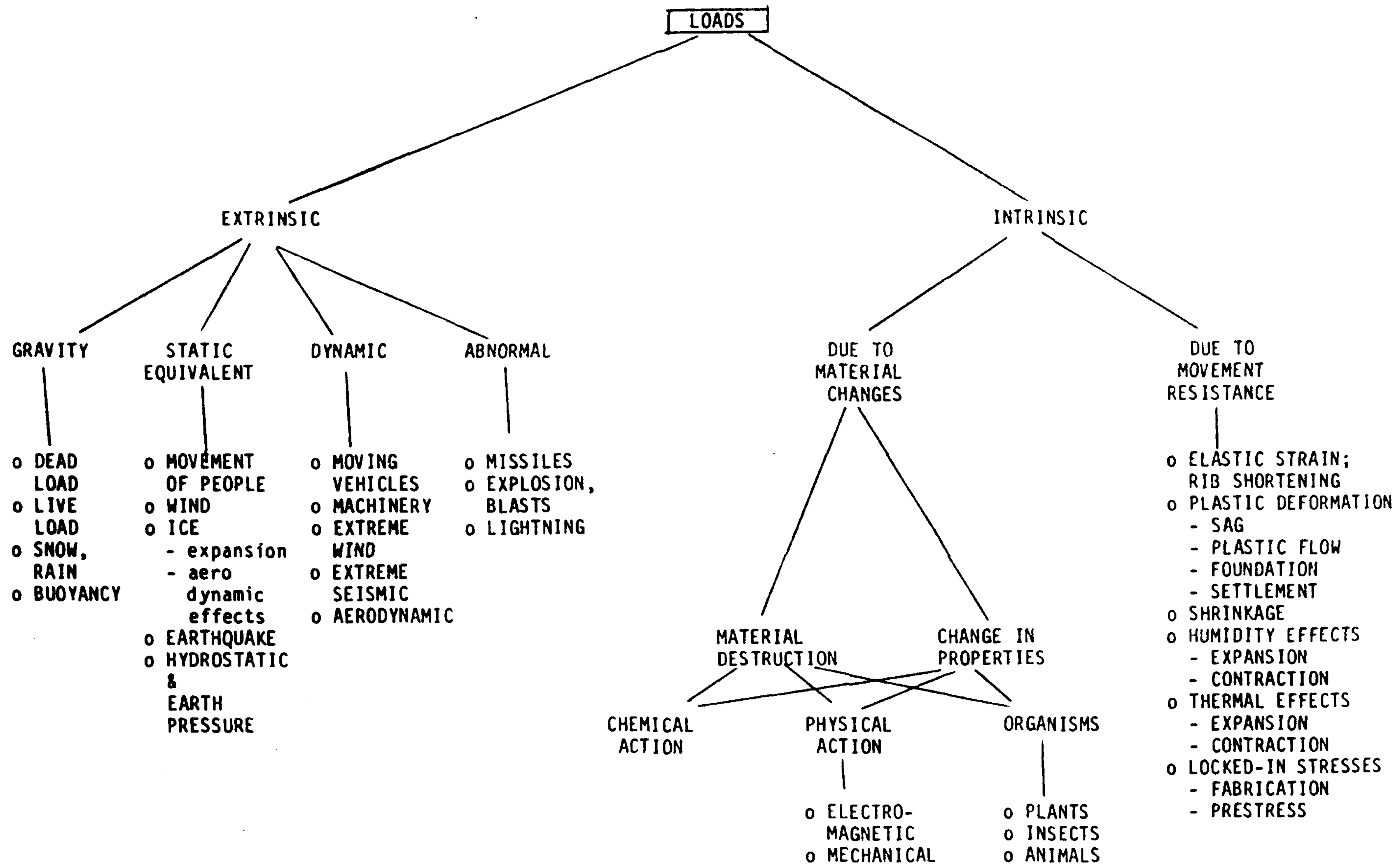


Figure 5. Load classification for analysis and design.

Table 1

Other Attributes That Can Affect Structural Performance

Habitability	Durability	Span Lengths	Maintainability
1. Health 1.1 Dust 1.2 Chemical 1.3 Radiation 1.4 Odors 1.5 Air Infiltration	1. Mechanical 1.1 Splitting 1.2 Tearing 1.3 Bursting 1.4 Fatigue	1. Flexibility; Range	1. Material Compatibility
2. Water Penetration 2.1 Absorption 2.2 Permeability 2.3 Infiltration	2. Wear Resistance 2.1 Abrasion 2.2 Scratches	2. Relation to Occupancy Indicated by Other Criteria (i.e., Load Carrying Capacity, Health, etc.)	2. Susceptibility to Cracking
3. Visual Characteristics 3.1 Reflectance & Contrast 3.2 Color 3.3 Texture 3.4 General Appearance	3. Dimensional Stability 3.1 Shrinkage 3.2 Expansion 3.3 Volume Change 3.4 Delamination 3.5 Cracks	3. Material Limitations	3. Resistance to Chemical Attack
4. Acoustic Characteristics 4.1 Reverberation 4.2 Reflectance & Dispersion 4.3 Absorption	4. Weathering 4.1 Freeze-Thaw 4.2 Fading, Color Stability 4.3 Bacteriocidal 4.4 Chemical		4. Repairability
5. Tactile Characteristics 5.1 Hardness 5.2 Roughness, Texture 5.3 Thermal Response 5.4 Scale	5. Theological 5.1 Plasticity 5.2 Viscosity 5.3 Creep		5. Cleanability
6. Ergonomic Characteristics 6.1 Scale Related to Human Body 6.2 Vibrations, Deflections, Movements			6. Ease of Inspection
7. Component or Building Image 7.1 Familiarity, Understandability 7.2 Clarity 7.3 Consonance With User Expectations			7. Potential for Remodeling
8. Thermal Properties 8.1 Expansion 8.2 Thermal Conductivity 8.3 Thermal Shock			

From an architectural viewpoint, most buildings consist of combinations of three basic elements--walls, roofs, and floors. Walls could be bearing-type or partitions, as well as exterior or interior. The location of bearing walls influences the definition of unobstructed space in the building. Also, structural walls can act as shear wall to resist lateral loads. Curtain walls or cladding, doors, windows, fixtures, and similar components are also affected by the building movement due to gravity, wind, and seismic loads as well as settlement. Openings which are too large or too numerous may weaken structural walls. Because of the freedom of geometry and lack of a need for rigidity in excess of what is required for its function as a horizontal structural diaphragm, the structural options for the roof are usually numerous. Moreover, the largest enclosed, unobstructed spaces are generally spanned by roofs. This is why most of the dramatic and radical spanning structures for buildings are those used for roofs.

Most floor structures are usually short in span, since loads are high on floors and flat systems are relatively inefficient. Therefore, when large unobstructed spaces are required in floors, important structural decisions are made in conjunction with architectural requirements for floor spaces and ceilings.

HVAC design concepts have evolved rapidly due to the energy shortage. The structural configuration and performance of structural elements can be affected by HVAC systems in a building. Similarly, power equipment/design and illumination technology are continuing to improve. These new systems can directly or indirectly influence the structure. Further, the design technology related to HVAC, acoustics, and electrical power and lighting systems can have a significant impact on the initial and life-cycle costs of the whole building system.

Another important system is the plumbing that provides water supply and waste handling in a building. This essential service system must be as independent as possible from the structure. However, this goal may not always be available since pipe runs, openings, chases, and other components may affect structural decisions.

It is evident from this discussion that structure cannot be totally isolated from the other building systems. Therefore, the building technology evaluation process must account for the performance attribute of structural integration with other major building systems. System integration may be extended to other structural subsystems (e.g., the foundation).

Selection of Major Attributes for the Evaluation

Because a structural system cannot be viewed as a separate entity of the building, an extremely large number of attributes characterize the performance requirements. An evaluation using this many criteria would be inefficient and impractical, if not almost impossible. Moreover, in some instances, there are overlapping or repetitious performance characteristics that are somewhat vague and difficult to quantify. Therefore, it is imperative to condense the number of attributes into a broad classification covering those most critical to this type of evaluation. Table 2 lists the major attributes selected for this study along with a brief explanation of each. Following each major attribute, the corresponding specific attributes also are listed according to the three basic stages of the building's life.

Major Structural Components

All buildings have a set of components that comprise the structural system (Table 3). Individual, localized structural actions by each of these components combine together through a phenomenon called "synergy," to provide the global structural action for the entire system. Therefore, structural attributes can be associated not only with the overall structural system, but also with all components of that system.

Table 2

Attributes Selected for This Study

1. **Structural Safety**:	Relates to the performance of structure and its components at the ultimate load. Ensures safety against collapse under overload conditions.	
Design:	1.1	Overloads
	1.2	Collapse safety/ ultimate strength
Construction:	1.3	Formwork/temporary supports
	1.4	Construction hazards
	1.5	Changing structure during erection and construction
	1.6	Material handling and quality control
Occupancy:	1.7	Strength against overloads
	1.8	Stability
	1.9	Collapse mode
	1.10	Fracture
	1.11	Fatigue
	1.12	Accidental/Special Loads
	1.13	Progressive Failure
2. **Structural Serviceability:**	Defines the structure's service behavior. Cracking, excessive deflections, etc., must be avoided, and the structure should be strong enough and in stable equilibrium under service or working loads.	
Design and Occupancy:	2.1	Loads and load combinations
	2.2	Strength properties
	2.3	Stiffness/vibrations

Table 2 (Cont'd)

	2.4 Strength to support loads
	2.5 Stable equilibrium/lateral bracing
	2.6 Roof ponding
3. **Fire Safety**:	Structure must be as safe as possible against fire hazards. In the event of a fire, the flame spread is controlled and strength is maintained for a predicted number of hours by providing adequate fire protection to the structural components.
Design, Construction and Occupancy:	3.1 Combustibility
	3.2 Flame spread amd potential heat
	3.3 Fire resistance and endurance
	3.4 Strength maintenance
	3.5 Collapse safety
	3.6 Protective devices
	3.7 Smoke propagation/toxicity
4. **Habitability**:	Defines livability in the building with regard to water penetration, acoustic environment, thermal characteristics, health, comfort, light, ventilation, and general safety in relation to structural scheme, planning, materials, building form, etc.
Occupancy:	4.1 Water penetration/permeability
	4.2 Acoustic environment
	4.3 Thermal properties/freeze-thaw exposure
	4.4 Health, comfort, light, and ventilation
	4.5 General safety
5. **Durability**:	Includes the ability of the structure and its elements to withstand wear and tear, weathering, creep and shrinkage effects, environmental and chemical effects, corrosion, etc. and maintain dimensional stability during the life of the building.

Table 2 (Cont'd)

Occupancy:	5.1	Mechanical properties
	5.2	Wear resistance
	5.3	Dimensional stability
	5.4	Weathering
	5.5	Rheological properties
	5.6	Environmental effects
	5.7	Corrosion resistance
6. **Constructibility**:	Ease of constructing the structural system, ability to surmount site conditions such as transportation, material handling, and erection, adaptability to prefabrication and unitized construction, tolerances, simple connection detailing, and other considerations.	
Design:	6.1	Structural planning
	6.2	Susceptibility to structural analysis
	6.3	Ease of detailing
Construction:	6.4	Material availability
	6.5	Availability of skilled labor and equipment
	6.6	Ease of erection and coordination
	6.7	Adaptability to prefabrication and unitized construction
	6.8	Required precision and tolerance/quality control
	6.9	Ease of material handling
	6.10	Reuse of temporary structures
7. **Maintainability**:	Includes material resistance to deterioration, corrosion, and chemical attack; repairability, ease of periodic inspection, potential for remodeling.	
Occupancy:	7.1	Material resistance to deterioration
	7.2	Susceptibility to cracking
	7.3	Resistance to chemical attack

Table 2 (Cont'd)

	7.4 Repairability
	7.5 Ease of periodic inspection
	7.6 Potential for remodeling
8. **Architectural Function**:	Includes building form and scale relationship, span and size limits of structural components, interior space definition, subdivision, and separation in relation to structural planning, building enclosure, and other elements.
Design and Occupancy:	8.1 Building form and scale
	8.2 Span and size limits of components
	8.3 Interior space definition, subdivision and separation
	8.4 Building enclosure
9. **Economy**:	Relates to the cost of materials, labor, and equipment, construction speed, ease of design modification during construction, maintenance and management costs.
Design and Construction:	9.1 Material
	9.2 Labor
	9.3 Equipment
	9.4 Ease of design modification during construction
	9.5 Construction speed
Occupancy:	9.6 Maintenance and management
10. **Compatibility**:	Includes compatibility of connecting elements, favorable interaction of joining materials, ability of structural members to receive and retain coatings.
Design and Occupancy:	10.1 Analysis of connections
	10.2 Connection detailing and simplicity
	10.3 Joining materials interaction
	10.4 Ability to receive and retain coatings

Table 2 (Cont'd)

11. **System Integration**:	The structural system must be integrated with the architectural design and other major building systems, e.g., power and lighting, temperature control, HVAC, plumbing, foundation, and possible mechanical and electrical enlargement during the occupancy of the building.
Design, Construction and Occupancy:	11.1 Architectural design 11.2 Power and lighting 11.3 Temperature control 11.4 HVAC 11.5 Mechanical/electrical enlargement during occupancy 11.6 Water supply and plumbing 11.7 Foundation system 11.8 Security system
12. **Code Compliance**:	Includes review of codes and builder's claim as to code acceptability, and satisfaction of any specific requirements or criteria in conformance with acceptable practice, standards, or reliable publication.
Design, Construction, and Occupancy:	12.1 Review of code 12.2 Satisfaction of specific requirements

Table 3

Major Structural Components

1. Foundations

    1.1 Conventional foundations
        1.1.1 Spread footings
        1.1.2 Strip footings
        1.1.3 Piles
        1.1.4 Caissons
        1.1.5 Mat
    1.2 Special foundations

2. Substructure

    2.1 Slab on grade
    2.2 Basement/foundation walls

3. Superstructure

    3.1 Floors
        3.1.1 Floor diaphragm/sheathing/slab
        3.1.2 Beams/girders/lintels
        3.1.3 Trusses/joists
    3.2 Roof
        3.2.1 Roof diaphragm/sheathing/slab
        3.2.2 Beams/girders/purlins/rafters/lintels
        3.2.3 Trusses/joists
    3.3 Stairs
    3.4 Bearing walls/shear walls
        3.4.1 Exterior walls
        3.4.2 Interior walls
        3.4.3 Bracing elements
    3.5 Columns
    3.6 Tension members
    3.7 Connections/joints
    3.8 Special elements

Design and Construction Requirements and Standards

A structural system can be investigated thoroughly by evaluating the system components in terms of each attribute listed in Table 2. The specific attributes can be cross referenced to USACE requirements for design and construction as well as other building codes and standards to allow a qualitative assessment. To provide this cross reference, construction codes and standards were surveyed to identify those applicable to the structural systems evaluation. The codes/standards adopted for this study are the Uniform Building Code (UBC) and the (BOCA) Basic Building Code. In addition, USACE regulations and DOD and Army regulations were scrutinized and the pertinent references identified. These codes and standards were then matched with the appropriate structural components and system attributes to define specific performance requirements. For example, it was determined that, to meet the "strength against overloads" requirement in the attributes list, the foundation must conform with UBC 2303(e) and BOCA 701.1. Appendix A provides a complete list of codes and standards used in the evaluation. Tables A1 and A2 of this appendix cross reference the standards to the attributes and system components defined in this chapter.

3 METHODS OF EVALUATING STRUCTURAL PERFORMANCE

Overview

As noted in Chapter 1, the evaluation method is structured to provide two types of information about a technology--quantitative and qualitative. The type of information that needs to be collected for a given attribute and structural component will be determined by the content of the code or standard. In general, these criteria call for some type of test to measure performance, usually at a laboratory scale, and result in the quantitative data. However, some evaluations depend on subjective engineering judgment, which constitutes the qualitative information.

To investigate structural components, three levels of evaluation are possible: analytical, experimental, and field study. Each level requires a specific set of tests to produce the data on which conclusions about a technology are based. For this study, five sets of tests were identified and are related to the evaluation levels as described below.

Analytical Evaluation

Two types of tests are possible at this evaluation level:

Test 1. Review of drawings and specifications. The drawings may include, but are not limited to, working and shop drawings for certain projects, sketches showing generic details for the structural system, and any other information presented graphically for the structural system or building technology.

Test 2. Review of numerical design calculations. The design calculations shall indicate the loading criteria (e.g., dead, live, wind, seismic), design assumptions, structural analysis showing how load effects are transferred and delivered to the foundations, and the resistance of member elements and connections to the applied loads.

Experimental Evaluation

The experimental level of evaluation can entail two test protocols:

Test 3. Assurance that component meets requirements of ASTM or other standard experimental or laboratory test (nondestructive tests or tests on models or samples).

Test 4. Experimental confirmation and verification of full-scale components and/or systems or subsystems in the laboratory or in the field, although it may not be specifically required by code.

Note that for Tests 3 and 4, the verification may be done through laboratory tests, experiments, or analyses conducted specifically for the evaluation, or may be based on existing test data or analytical documentation to minimize cost. Test data need not be by independent testing agencies as long as the data appear to be reliable.

Field Testing

This evaluation method is self-explanatory and is defined as:

Test 5. Field investigation during design phase, construction and/or occupancy, including firsthand information on products and building technologies gained by visiting the manufacturing plants, shops, and other facilities.

Test Objectives

The tests listed above are prescribed in various combinations to assure that a product or system conforms with performance criteria. The combination of performance requirements, performance criteria, and tests for any given system are the performance specifications for that system. The performance characteristics completely describe the performance concept as an integral part of the systems approach to construction of any building. The three levels of evaluation are described for various loading conditions below.

Analytical Evaluation Method (Tests 1 and 2)

The analytical method is based on mathematical analysis of the structure or component for a particular attribute by numerical computations or computer simulations. The analysis is performed on the idealized structural system or component and is aimed at determining its response characteristics (i.e., internal forces, deformations) when subjected to extrinsic or intrinsic loads (see Figure 5). This method of evaluation uses Tests 1 and 2 as described above.

Building Analysis for Gravity and Wind Loads

A building structure is normally analyzed for gravity (dead and live) and wind loads to determine the stability of a system (e.g., bracing, shear walls, diaphragms) the lateral sway caused by wind loads and possible asymmetrical gravity loads. An analysis of the member elements is required to determine internal member forces, bending stresses, shear stresses, torsional stresses, member deflections and similar properties. There are many analysis techniques available and the design professional can adopt a suitable technique for this purpose.

Analysis for Tornado and Hurricane Loading

Tornadoes usually begin with severe thunderstorms and are atmospheric vortices that extend from within the cloud to the ground like a funnel. Almost all parts of the United States are prone to tornadoes in various degrees. Tornado wind speed can be as high as 300 mph, but most tornadoes that occur in the United States have maximum wind speeds less than 150 mph. The perception of this lower wind speed makes tornado-resistive design possible. Tornado intensity is usually rated by the Fujita-Scale (F-Scale).

Distinguishable degrees of protection are required for different types of buildings. Usually, for occupant protection, it is not economically feasible to design the entire building to resist tornadoes. Only a small area of a building needs to be strong enough to shelter people in the event of a tornado.

A hurricane is a severe tropical cyclone that develops over the North Atlantic Ocean, Caribbean Sea, Gulf of Mexico, or Eastern North Pacific Ocean. These storms affect the well populated Gulf and East Coast areas of the United States and occasionally the West Coast. Winds frequently reach speeds of 100 to 135 mph, with the most severe storms possibly reaching a wind speed of 200 mph. Hurricane intensity is usually rated according to the Saffir/Simpson Potential Scale. Many aspects of hurricanes are not well understood and important data are still required, despite many studies on this subject. As a result, buildings subjected to hurricanes and high winds are designed with the same concepts stated in standard codes of practice for regular wind loads, although the value of the corresponding wind pressure is increased.

Analysis for Earthquake Loading

The major seismic zones in the United States include several areas where major population centers exist. The proper design of buildings to resist earthquake ground motions requires a number of

considerations, including: careful layout or configuration of the building, thorough evaluation of all connections, the incorporation of ductility and redundancy into the structure, and an evaluation of the consequences of failure. These special requirements are in addition to the normal analysis and design procedures and are essential if the structure is to perform well. The building structure is usually analyzed for the equivalent static earthquake loading following specifications of the prevailing building codes. The analysis is performed to determine the internal forces and deformations of the structure and its components for a specified design earthquake loading. Results are then compared with selected performance criteria determined from applicable codes. For slender buildings with large periods of vibration or buildings with complex form or configuration, dynamic analysis for the earthquake loading may be required.

Analysis for Abnormal Loading

Buildings occasionally may be subjected to abnormal and accidental loads, such as explosions, blasts, and missiles. Analytical techniques for these loads are rather poorly defined at present, but some are available in the literature. When the possibilities of such loads exist, due consideration must be given to account for them fully in the structural design process. Analysis of this kind is not normally required for most building structures, but is included in this discussion for completeness.

Other Analyses

Special analyses are required for long-term effects (e.g., creep, shrinkage), thermal loads, fire resistance, cyclical loads, and progressive failures caused by repeated and/or accidental loading. These analyses are usually required for special conditions and are warranted whenever the design professional has any doubt about the structural system's performance under such conditions. For most routine structures, these analyses are not required.

Review of Documents

During an evaluation, all documents related to structural analysis and design need to be reviewed and checked for compliance with the appropriate performance criteria. Documents to review include design drawings, shop drawings, construction specifications, design calculations, and other available materials. The specific performance requirements in Table A1 (Appendix A) for which certain performance criteria are identified as mandatory or desirable could serve as a checklist for this review process. As stated earlier, this level of review corresponds to Tests 1 and 2. While reviewing the documents, it is necessary to ensure that all USACE and other selected building code requirements and criteria are met by the building technology in question.

Experimental Evaluation Methods (Tests 3 and 4)

The experimental evaluation method is based on laboratory tests on models, samples, or prototypes of the structural system/components. These tests validate a theory or assumption and ensure quality control. The lack of simple and general relationships between the various performance variables, material characteristics, and loading and geometric parameters often leads to the necessity for performing experimental simulations in the laboratory or field.

Tests on Models and Samples (Test 3)

Experiments conducted in the laboratory on scaled models of components or samples of materials are generally required for simulating component response to loads and ensuring quality as is prescribed by the code. Model testing usually involves a dimensional analysis and may include structural laboratory tests for stress-strain characteristics, deflection, torsion, and other properties. It may also involve photoelastic experiments, wind tunnel tests, shake-table tests, and non-destructive testing. For material

tests, the standard requirements of ASTM or any other codes related to materials usually are to be followed. The results of all such tests must be well documented and the evaluator must review these documents during the evaluation process.

Full-Scale Structure and Component Tests (Test 4)

Much experimental work has involved load tests on components. These tests often are done in the laboratory environment in conjunction with simplified analyses to account for system interaction. These simplifications ignore the complex, intricate strengthening effects of other structural and nonstructural elements. Thus, despite the merits of such component tests, the results can be misleading.

Full-scale system tests coupled with mathematical analysis are very useful in predicting the structural response to loads. However, for large buildings, such tests are prohibitively expensive and difficult to interpret unless they are performed under laboratory conditions. Large-scale subsystem tests to simulate total system behavior in the laboratory environment or field offer a more reasonable approach. Experimental results from these tests need careful review to ensure that performance meets the stated criteria.

Field Investigation Methods (Test 5)

The evaluator can inspect a building that uses the candidate technology to obtain information about its performance. This inspection can be done during construction or when the building is occupied. During construction, the inspector may observe how construction is proceeding, the workmanship, and advantages and disadvantages of the technology. Similarly, during the occupancy stage, the building should be inspected to determine if it has performed well so far. As an alternative, when a building is *not yet built*, the evaluator can visit the manufacturers' plants to gain insight into their degree of sophistication during typical operations.

Field investigation is very desirable. A checklist of items to be investigated can be prepared to conduct the evaluation in a systematic manner. The checklist could include relevant items from Table A1 (i.e., the evaluators would select the items from Table A1 that they want to investigate in the field). Accurate documentation during the field investigation is essential. This type of evaluation corresponds to Test 5, as described above. Therefore, the specific requirements that indicate Test 5 (see Table A1) could be incorporated into the checklist. Evaluators can include any additional observations related to structural performance in their field investigation records.

Other Methods of Evaluation

The evaluation methods described above are objective and quantitative, and are based on scientific, systematic review and verification. There are, however, other methods of evaluation that are based on existing structures and are qualitative (subjective). These methods are quite important in that they are based on the accumulated experience or judgment of faclity users, designers, contractors, and manufacturers. These methods are experiential and have some element of arbitrariness. However, they must be included in the evaluation process to arrive at a rational evaluation scheme.

Although it may be difficult to obtain statistically significant data for existing structures in many cases, the evaluator should attempt to collect as much information as possible. The larger the information base is, the more meaningful the evaluation.

4 INFORMATION REQUIRED FOR AN EVALUATION

Collecting and organizing information are important stages of the evaluation process. It may be practical to develop a construction information system to store different types of data that may be useful in the present or future evaluation studies. In-house libraries and information retrieval systems can be developed for the system-specific data collected. Development of such a data base will eventually lead to an efficient approach toward evaluating feasible systems and selection of the best candidate if a selection strategy becomes necessary.

After the specific performance requirements and the corresponding tests are identified from Table A1 for a particular structural system, the data required to make an evaluation and substantiate the evaluator's findings must be verified. In general, all basic data can be classified into two broad categories:

1. Engineering data: these are based on design, construction, and experimental data that can be related to codes, standards, and USACE design and construction criteria. The standards will typically correspond to ACI, AISC, AITC, ASTM, and others. These data are verifiable, tangible, and reproducible, and are based on scientific findings.

2. Empirical data: these are based on past performance, user satisfaction, observed changes in the structural system and components, the period of observed performance, and similar information. These data are qualitative and not necessarily verifiable. They are based on experience, input from professionals, and historical findings.

The specific types of data to be collected for a structural evaluation are described below. These include a combination of engineering and empirical data.

Structural Design Data

Accurate design and research data are required for evaluating a specific structural system. The design data will typically include a description of the system, the design criteria, design and analysis calculations, graphs or charts developed for repetitious element design, and references to specific building codes, standards, or relevant research findings. These data must be reviewed thoroughly by the evaluator. Any deficiency in this area, particularly omission of significant design criteria, must be noted. These data will be compared with the USACE and other selected structural design criteria to determine compliance. Design data for all components must be checked in the manufacturer's design manual and calculations. If the manufacturer's information appears inadequate, evaluators should analyze the structural component or element themselves.

Construction Data

For collecting construction data, it is important to review construction documents for a completed project that used the same technology when these records are accessible. First-hand knowledge about a system can be obtained by visiting a structure under construction, systematically recording the field data, and if possible, monitoring the project and requesting feedback from participants. This information can be checked against the applicable construction criteria. Some of the constructibility features that need to be reviewed are: fabrication or erection tolerances, safety and stability during construction, ease of scheduling, fit-up problems, susceptibility to damage or loss of strength during construction, and ease of installing members and connections.

Data From Experimentation

Valuable data on a structural system can be obtained from experiments conducted to verify the capacities of structural components when analytical verification is not possible or when the analysis would be too inadequate, unrefined or complex. Further, data related to full-scale or subsystem tests are required on many systems for proper evaluation. Documented results and their interpretation must be reviewed. Testing agencies and experimental research organizations may provide valuable assistance when additional interpretation is necessary. The evaluator must also decide if new or different tests or experiments are desirable for a particular structural system. It is emphasized, however, that for economy and expediency, existing experimental data should be used whenever possible, provided these data are reliable and sufficient. Existing data, if valid, preclude the need for additional experimental determination or verification.

Data Related to the Completed Building

Past performance data should be gathered for completed structures that use the technology under study. Documented failures or inadequacies will help in the system appraisal and may result in improved design decisions and judgments for future projects. Feedback from occupants, design/ construction teams, and consultants for different projects often provides valuable insight into the system's suitability in terms of structural performance and economy. Some items to note in completed buildings are: cracking, water penetration, noticeable floor deflections, bowing of walls, roof ponding, shear cracks around door and window openings, and highly flexible floors.

5 SYSTEMATIC BUILDING TECHNOLOGY EVALUATION PROCEDURE

Evaluation Approach

The systematic methodology developed in this study is intended for use in evaluating existing as well as new technologies. The complexity of current building technologies demands a structured approach to building technology evaluation and forecast. Further, the complexity of information on building design and construction requires that performance attributes be linked to the collected information in some meaningful way.

Such an approach has been discussed in general terms elsewhere.[1] In addition, a systematic approach for evaluating construction materials has been reported.[2] The present study adopts an approach similar to these published methods. The approach taken here, however, focuses on structural systems and their performance. This evaluation approach is therefore specific to attributes and data that describe the performance of building structures and components.

Determining Evaluation Criteria

Performance requirements can properly define user needs, constraints, and impacts. The objective is to satisfy the client's needs and aspirations, which rely heavily on performance requirements. As such, identification of criteria for evaluating a building technology must reflect the anticipated performance for the structural elements and the total structural system.

The major performance attributes in Table A1 can be taken as the criteria for evaluating structural systems. These attributes are sorted into categories referred to as "specific attributes or performance requirements" in Table A1 to elaborate upon the major attributes. These specific requirements, when satisfied (or not) via the performance criteria extracted from USACE and other codes, regulations, and standards of practice, determine a technology's degree of acceptability. The level of risk acceptable to the client, if known, will greatly influence the determination of acceptability by the evaluator.

Weighting Attributes

After selecting the evaluation criteria, which are the major performance attributes in this case, their relative importance needs to be determined. This can be done by assigning a weight factor to each criterion or attribute. Factors can be weighted in many ways. One approach is based on input from clients, users, design professionals, consultants, contractors, and specialists for a particular building technology. These professionals must be familiar with the technology. A more general approach is to develop a data base of information based on input from the various professionals. The latter approach was adopted for this study and an attribute rating sheet was sent to different organizations for buildings with different types of occupancy (see Appendix B for details). Based on responses from these professionals, the weighting factors presented in Appendix B were determined.

---

[1] T. R. Napier and L. M. Golish, *A Systems Approach to Military Construction*, Technical Report P-132/ADA123382 (U.S. Army Construction Engineering Research Laboratory [USACERL], November 1982).

[2] H. J. Rosen and P. M. Bennett, *Construction Materials Evaluation and Selection* (John Wiley and Sons, 1979).

Rating of Structural Systems

It is desirable to develop a graphic presentation showing the attribute-information relationship to summarize all significant aspects of the evaluation. This presentation would depict the relationship of selected attributes to the engineering and empirical data collected. Each specific performance requirement that belongs to a subset of a major attribute can be tested and linked to the established performance criteria. Any deficiency in the performance of a structural component can be highlighted so that the component can be modified to meet the performance criteria (regraded). Such a representation can also be used to record past performance data (particularly information related to structural failures or inadequacies) for future reference or use by others.

Developing a Rating Sheet

Once the evaluation criteria have been identified, a Rating Sheet can be developed for a structural system that uses the specific building technology. The data are divided into two parts--engineering and empirical. Under the "Engineering Data" heading, the information sources/bases are shown. Similarly, under the "Empirical Data" heading, the historical and experiential sources and observations based on these sources are shown. Figure 6 is a sample Rating Sheet.

The "USACE" and "Codes/Standards" columns under the "Engineering Data" heading correspond to the performance criteria with reference to applicable code sections/clauses indicated under the "Code/Standards Reference" column in Table A1. Table A2 summarizes the performance criteria found in USACE regulations. These criteria were extracted from USACE documents (after a review of USACE, Army, and DOD standards). Since USACE regulations are somewhat scattered throughout the different engineering disciplines, such a summary is very useful and convenient for the evaluator. Appendix A can be updated with new knowledge and information on the regulations on the basis of a more extensive review by more than one expert.

For the other codes, e.g., BOCA and UBC, these criteria are readily available, and hence are not stated separately. The code section numbers for the applicable specific attributes are presented in Table A1. Also, when USACE refers to standards, e.g., ACI or AISC, the applicable criteria are not stated since they can be readily found in those specifications or manuals.

The "Full-Scale Tests" column refers to any completed full-scale test on a structural system or subsystem in which appropriate test and performance criteria were adopted by the experimenters. These test criteria should include, as a minimum, the criteria for full-scale model selection and loading simulation. The performance criteria should at least include the strength and stiffness criteria in accordance with applicable codes and standards. The "Model/Sample Tests" column should include tests specified by ASTM, ACI, and similar standards organizations. A list of these standards in relation to various attributes is available as Appendix E of USACERL Technical Report P-132. The "Field Investigation" column is intended to record quantitative data gathered during site visits and not included under the other information categories.

The columns under the "Empirical Data" heading correspond to qualitative data obtained from input by professionals through interviews, site observations, research, publications, and similar sources. This information base is very important because it is based on people's experience and reflects the practical considerations of the real world.

The evaluator's task is now to assign rating points to each attribute in relation to each column under "Engineering Data" and "Empirical Data" headings. These points are based on a suitable rating

Building Technology:

Attribute (N=12)	Engineering Data				
	USACE/Army/DOD Regulations	Codes/Standards	Full-Scale Tests	Sample/Model Tests	Field Investigations
1. Structural Safety					
2. Structural Serviceability					
3. Fire Safety					
4. Habitability					
5. Durability					
6. Constructibility					
7. Maintainability					
8. Architectural Function					
9. Economy					
10. Compatibility					
11. System Integration					
12. Code Compliance					
Total Score					

Figure 6. Example Rating Chart.

Empirical Data					Score X	Weight Factor, Y	Weighted Score S=(X)(Y)
Past Performance	Time Frame of Performance	Observed Changes	Client/User Satisfaction	Future Potential			

Cumulative Score Rating = S S =

System General Rating

$$= \frac{SS}{N} =$$

Figure 6. (Cont'd)

scale that can be entered into the Rating Sheet shown in Figure 6. To arrive at a rating for an attribute, the evaluator must study all data and test the criteria for the affected structural component, as discussed before, and then use rational, unbiased judgment. This judgment rating is only an index of the degree of satisfaction achieved by an evaluator completing the evaluation scheme for a specific attribute. A proposed rating scale is:

Degree of Satisfaction for Attributes	
Outstanding	= 6
Far above average	= 5
Above average	= 4
Average	= 3
Below average	= 2
Far below average	= 1
Unsuitable	= 0
Not known/Not applicable	= 3

Note that for "Not Known" and "Not Applicable," a rating of 3 (i.e., a median value) is indicated because a structure or a component cannot be underrated or penalized with regard to an attribute if the data are totally unknown or unrelated. Conversely, a structure or a component should not be overrated since the lack of knowledge or applicability cannot be equated to an "Outstanding" or higher degree of satisfaction. Since these data do not affect the attribute, an "Average" degree of satisfaction is assumed.

After entering points into the Rating Sheet, the total score, X, for each attribute is determined. The weight factor, Y, for the structural system under evaluation for each attribute (determined in Appendix B on the basis of input by professionals for a particular type of occupancy) is entered into the next column. The weighted score, [S=(X)(Y)], is entered into the last column. The total of all weighted scores for the N attributes (N = 12 in this study) gives the Cumulative Score Rating for the system when rounded to the nearest whole number. The Cumulative Score Rating, when divided by N, is the System General Rating (SGR) for the technology. The SGR value is an index that reflects a technology's degree of suitability for use by USACE, and is expressed as an integer.

For a perfect structural system (which is, of course, impossible), the Cumulative Score Rating is 10 x 6 x 13 = 780 and the SGR is 780/12 = 65. On this basis, the following scale is recommended for determining the suitability of a particular structural system:

SGR	Performance Rating
52 and over	Excellent
45 - 51	Good
40 - 44	Fair
39 and less	Poor

An "excellent" structural system (or building technology) is one that will ensure highly satisfactory performance. Such a technology should be seriously considered by a prospective user as a structural system that meets the requirements and standards of sound construction practice.

A "good" structural system is one that is expected to perform better than average and also is generally satisfactory in terms of structural integrity and adequacy. However, the system is likely to have some disadvantages that lowered its rating and the user should thoroughly investigate these limitations before deciding to adopt such a system.

A "fair" structural system represents average performance with a number of major limitations. The user must exercise extreme caution in deciding to adopt this system.

A "poor" structural system is generally unsatisfactory or even unacceptable and the user is advised not to adopt it.

It is reemphasized here that the SGR value is only an index providing guidance to a prospective owner on the suitability of a particular structural system. Limitations of the rating scheme that forms the basis for the SGR value were discussed above.

Comments on the Rating Scheme

The rating scheme developed here has the advantage of demonstrating an objective, verifiable approach to building technology evaluation and forecasting. Also, it is flexible enough to be modified and updated as new information becomes available. Further, by providing a systematic numerical procedure, the rating scheme can be computerized and used for building system selection to provide effective procedures and guidelines for evaluators and decision-makers.

There are, however, a few limitations to this scheme. No matter how objective and quantitative this procedure is, there will always be an element of qualitative judgment behind the numerical scores and the rating which may sometimes be biased or insufficient. The process of information collection and performance criteria development can never be fully "completed." Also, the SGR value for a structural system should only be taken as the best possible index determined on the basis of the most diligent efforts, and represents only a norm that can be adopted as guidance for preliminary system selection.

One crucial factor may invalidate the outcome of the evaluation study. A system may have a high SGR value, but it may be too expensive for a client or may not match his/her specific needs and, hence, the SGR does not mean much. Therefore, the client's degree of accepted risk, affordability, personal inclinations, and other considerations may determine the suitability of a particular system. However, even when these unpredictable, qualitative factors are not considered, the SGR value can provide a realistic indication about the overall performance of a structural system based on rational judgment and scientific/engineering verification.

Developing an Evaluation Worksheet

To rate each major attribute, it is necessary to evaluate the subattributes or specific attributes under each major category. For each specific attribute, the evaluator must begin the process by identifying the structural component affected and the test required from Table A1. Then, from Table A2, the applicable USACE, Army, and DOD criteria for the structural material can be located and the structural system or component checked for compliance. Similarly, the evaluator can review the other building code requirements in Table A1 and check for compliance with these. The compliance with USACE/Army/DOD regulations and building codes/standards must be ensured by reviewing the drawings, specifications, design calculations, and other documents as discussed earlier. Similarly, the results of full-scale load tests and model/sample tests must also be reviewed and evaluated. Further, the information gathered from field investigations and site visits by the evaluator will be interpreted and evaluated.

For each specific attribute, the above observations will be recorded and evaluated using a scale ranging from unacceptable to excellent. No relative weighting factors or numerical points for the specific attributes are suggested because this convention would lead to considerable complexity. (However, such a method could be pursued in a future study). The following qualitative rating scale for each specific attribute is recommended:

Scale of Evaluation of Specific Attributes

Excellent	- E
Good	- G
Fair	- F
Satisfactory	- S
Poor	- P
Unacceptable	- U
Unrelated/Unknown	- N

Note that the above scale is not essential since the evaluator can arrive directly at numerical points for each general attribute from the Rating Sheet in Figure 6. However, an evaluation scale for each specific attribute will reveal deficiencies in the structural system more readily and assist the evaluator in determining the numerical points for each attribute within each information category presented in Figure 6.

The evaluation process can be facilitated by the Attribute Evaluation Worksheet, a sample of which is shown in Figure 7. It is important to note that the documents prepared by the evaluator will be used to communicate significant characteristics of building technologies to others not necessarily familiar with the technology in question. Therefore, the commentary entries in Figure 7 should be brief, but complete and clear, to accurately represent the technology's performance relative to the attribute being considered.

The evaluator can now enter scores, based on his/her overall degree of satisfaction for each attribute, under the "Engineering Data" heading in Figure 6. Evaluation of attributes under "Empirical Data" will be based on interviews, input by professionals, publication reviews, and similar methods. Since these data are qualitative, there is no need to develop an evaluation worksheet for this part of Figure 6. The evaluator can enter scores directly into Figure 6 based on personal judgment and interpretation of the subjective data collected. It may not be easy to collect this "Empirical Data" for many reasons (e.g., political, lack of availability of past documents, inability to contact well informed people, time constraints). The evaluator should, however, solicit as much information as practical to support the best possible qualitative evaluation of a structural system.

Note that, while checking different criteria for each specific attribute, a large amount of data needs to be reviewed. The evaluator is expected to review these voluminous data to his/her satisfaction, but not necessarily include them in the Evaluation Worksheet because that would be an extremely time-consuming tedious process. However, the evaluator may, in some cases, wish to record, catalog, and manage these data. Information also can be organized into data bases for future reference.

It is emphasized that the evaluator using the evaluation method developed in this report must be a qualified professional with considerable experience in building technology and structural design and construction. Although data can be collected and processed by an evaluation team, the points in the Rating Sheet must be derived by professionals or personnel under their direct supervision.

The Evaluation: Step-by-Step Instructions

This chapter has presented a very detailed account of the evaluation procedure. To summarize, the following steps are required for evaluating a structural system or component:

Step 1. Establish and identify the performance criteria for each specific attribute (or subattribute) for the particular structural system. This process is facilitated by Tables A1 and A2 in Appendix A, which contains appropriate references to USACE/Army/DOD regulations and to approved codes/ standards.

Step 2. Then determine what action is required to test the performance of a structural system or affected component by consulting the "Required Test No." column from Table A1. A checklist of items that need to be investigated can be prepared to help guide the evaluation process.

Step 3. Collect information to support an evaluation. Examples are drawings, specifications, design calculations, laboratory test results, and field investigations, which constitute the objective part of the evaluation (i.e., the first five columns of the Rating Sheet, shown in Figure 6).

Step 4. Based on the information collected in Step 3, complete the Attribute Evaluation Worksheet (Figue 7) with observations and comments related to the system's success or failure in meeting the performance criteria. Assign a letter rating for each specific attribute. This rating will be useful for making objective judgments about each specific attribute. The numerical judgment rating for each attribute is, however, based on your *overall* degree of satisfaction and is entered in the lower part of Figure 7 after each specific attribute has been considered. Transfer these points as scores to Figure 6 under the "Engineering Data" heading.

Step 5. Obtain an appraisal of the structural system in terms of the attributes from developers, owners, designers, and current users, if possible, through questionnaires or by telephone or personal interviews. Obtain scores based on your degree of satisfaction from the interviews and from reviewing publications and enter these in Figure 6 under the "Empirical Data" heading.

Step 6. Add the scores along each row (i.e., for each attribute) in Figure 6 to achieve score X and multiply this value by the weighting factors Y from Table B2 for the appropriate type of occupancy to obtain the weighted score S. Enter this score in the last column of Figure 6.

Step 7. Add the weighted score S for all of the N attributes to obtain the Cumulative Score Rating. The SGR is next obtained by dividing the Cumulative Score Rating by the total number of attributes, N.

Building Technology:

Attribute No.: Name of Attribute:

Specific Attribute	Observation/Comments	Rating

Rating of Attribute for "Engineering Date":

USACE/Army/DOD Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigations

Figure 7. Example of Attribute Evaluation Worksheet. Material codes are listed in Appendix A.

6 EVALUATION OF THE TUNNEL FORMING SYSTEM

Volume I of this report describes how the prototype BTFE cycle was used to identify 21 building technologies with potential application to USACE. After the first three steps of the cycle were completed, two building systems emerged as the most promising: the Tunnel Forming System and the Composite Panelized System. Each technology was evaluated independently using the detailed procedure described in this volume for investigating structural systems and components.

Structural System Description

Concrete is often used as a structural material for modular building construction. One concrete system, called the Tunnel Forming System, originated in Europe, and has been used primarily in California and Florida in the United States. With the Tunnel Forming System, slabs and walls are poured simultaneously using reusable sheet metal half- or full-tunnel forms. Full-tunnel forms look like an inverted U from the end, and half-tunnel forms look like an inverted L from the end. The soffit form and wall forms are all one piece of formwork, erected and stripped as a single unit. Use of half or full tunnels depends on the room width, form weight, and crane capacity. The form size is adjustable to match the specified size of the room or building unit. Descriptive brochures by Outinord Universal Co. and Aarding Forms are included in Appendix C, along with sketches showing these system concepts.

Information Collection

Contacts for obtaining information from the manufacturers/promoters of the building systems were identified from in-house sources. For the Tunnel Forming System, the following two organizations were contacted:

1. Outinord Universal Co.
   21 N.E. 166th St.
   North Miami Beach, FL 33162
   Telephone: (305) 947-3852

2. Aarding Forms Inc.
   8034 Deering Ave.
   Canoga Park, CA 91304
   Telephone: (818) 883-4990

Initial information was collected by telephone interview. Later, these organizations sent technical manuals and other literature. Further data information was gathered by field trips to Aarding Forms, Inc., and Outinord Universal Company.

While in California, the evaluator discussed the Aarding forms and system with Mr. Ivan Warren, Vice-President, and Mr. Jacques Swatz, Managing Director, on December 16, 1987. Aarding is a small firm with a few full-time employees. The production plant is located in Holland and the tunnel forms are imported to the United States. Mr. Schwatz explained the technical details of the system and Mr. Warren explained the other general and nontechnical aspects. Mr. Warren emphasized the economy and convenience of the system and the advantage of accessibility to European technology. He also provided several contacts who have been involved with this system as designers, contractors, users, and developers. Mr. Warren provided photographs of buildings in which the Aarding system has been used. The evaluator

documented all relevant data necessary for the evaluation. Design calculations for this system were done by structural designers following ACI and other applicable codes.

In Florida, the evaluator met with Mr. Dick Doster, General Manager of Outinord Universal Co., on March 8, 1988. Outinord is a small firm with a few full-time employees and represents the largest tunnel forming operation in the United States. The production plant is located in France and the tunnel forms are imported. Mr. Doster and Mr. Michel Rybarczyk explained the technical, nontechnical, marketing, and construction details of the system.

The evaluator also met with Dr. Tseng, who owns a separate structural consulting firm and consults for projects that use the Outinord Tunnel Form. Dr. Tseng explained the structural design details of this system and answered questions posed by the evaluator. Mr. Doster and Mr. Rybarczyk accompanied the evaluator to several construction sites in the Miami Beach area where tunnel forms are being used for residential apartment and condominium projects. In addition, Mr. Doster showed the evaluator some completed projects. Altogether, 10 sites were covered. The evaluator took pictures of both the completed and in-progress projects. Mr. Doster also gave the evaluator photographs of completed projects and some sketches, along with the names of contacts who could provide specific information on tunnel forms. The evaluator obtained enough data fo n evaluation and also inspected other documents made available. On March 9, the Evaluator visited the Caribbean Bay Hotels (one of the 10 sites) which were under construction near Epcot Center at Disney World. This complex project used Outinord Tunnel Forms.

Evaluation

The Tunnel Forming system was evaluated following the systematic procedure developed in this report. Details of the numerical evaluation are presented in Appendix D. The Rating Sheet appears as Table D1. The objective part of the evaluation under the "Engineering Data" heading was derived from the Attribute Evaluation Worksheets (Appendix D). The subjective part of the evaluation was based on the interviews, publications, telephone surveys. A list of persons contacted is included in Appendix E.

Results

The SGR value determined for the Tunnel Forming System is 49 (Table D1). Thus, it appears that the Tunnel Forming System is suitable for USACE construction of residential buildings since it is slightly above the "good" range (i.e., it is expected to perform better than average). However, before deciding to select this system, further investigation is required for the issues that lowered the rating from "excellent" to "good." Major advantages and limitations of the system are described below.

Advantages

The evaluation found the following advantages of the Tunnel Forming System:

- Because of the modular construction and mechanized forming technique, construction speed is a major advantage. It is estimated that concrete for about 2500 to 3500 sq ft* of floor can be poured in a single day.

- Concrete has an excellent finish and can be textured easily.

*A metric conversion table appears on p 49.

- Electrical conduits and other pipes can be placed and concrete cast in an orderly sequence because of the modular type of construction.

- The system might be more economical than conventional systems for large construction projects. However, this would need verification.

- Once a modular type of construction is selected by the owner, architect, and others involved in a project, there is considerable architectural freedom for configuring the building in specific modules. Modular construction also is very suitable for residential construction.

- The Tunnel Forming System is adaptive to prefabricated or unitized construction.

- This sytem actually is a concrete forming technique and not a structural system. No new structural concept is involved. Therefore, the structural integrity of a tunnel-formed building would be similar to a reinforced concrete building. Codes and regulations are identical to those for any reinforced concrete building. Being rigid, buildings constructed with tunnel forms are structurally very adequate and expected to perform well, even in seismic zones.

- Other positive aspects of concrete modular construction are predicted to be energy efficiency, adaptability to humid environments, durability, acoustics, and fire resistance; more substantive data would be required to verify some of these claims.

- The maintenance cost is low.

Limitations

The Tunnel Forming System also was found to have limitations, as summarized below:

- It is uneconomical for small projects. Economy is achieved for a project when the floor area is at least 50,000 to 100,000 sq ft as for barracks and hotels, and where the architectural configuration is very linear. For rental projects (e.g., apartments, town-houses), the feasible minimum floor area is approximately 200,000 to 250,000 sq ft. These estimates are based on builders' experience and require verification through an economic analysis.

- Because the system is modular, it demands rigorous project planning and systematic scheduling. A high degree of coordination is essential. Therefore, construction may be halted if there is a breakdown or delay during any one phase since the system depends on strict, progressive scheduling. (It is noted, however, that a strict schedule may yield a better product in some instances.)

- Initial mobilization of the tunnel forms is difficult because the forms must be ordered, delivered, and set up before construction can begin. (Once the speed of construction has been established successfully, the mobilization effort diminishes to the extent of any routine construction method.)

- Since the Tunnel Forming System depends on a production-oriented method of construction, personnel experience, skill, and training are vital to the success of a project. As a result, this system may not be cost-effective in areas where labor rates are high or there is a unionized labor market.

- In residential construction, it is sometimes necessary to modify the building configuration. This is difficult, if not impossible, with tunnel formed buildings since the concrete walls are permanent. Architectural planning of buildings using this system must be done keeping this fact in mind.

- The initial building design must be specific to tunnel forms. Therefore, designers must wait to start the design process after the decision to use a Tunnel Forming System has been made. However, this system may be suited to plans not originally intended for tunnel forms with some adjustments.

- The cost of a tunnel forming operation could be considerable if a construction project is located in a remote area. The need to ship the forms to the site and the absence of an infrastructure will increase overall cost.

Summary of Findings

To summarize the evaluation results:

1. The Tunnel Forming System is suitable for residential-type, low-rise Army facilities. The system generally conforms to existing USACE criteria. It could be modified to include any new USACE criteria unless they depart drastically from existing ones.

2. The Tunnel Forming System is expected to perform well and cater to the overall needs of USACE residential construction projects.

3. The Tunnel Forming System meets the general requirements of good construction practice and standards, and can be used for non-USACE construction projects as well.

4. The system has some limitations that should be considered by the design professional or evaluator before making a final decision on its suitability.

In general, however--regardless of the system's limitations--it appears to be suitable for USACE construction. Actual use of any system will largely depend on many considerations (e.g., budget, project goals) other than the structural performance of a system. In particular, since the cost of a structural system is important to the owner, it is recommended that a comprehensive economic analysis be conducted to compare the candidate system with other currently available structural systems.

It should be noted that no full-scale tests were conducted for the Tunnel Forming System. Although such tests are not required by codes, they are desirable for new systems. Since the Tunnel Forming System is not a new structural concept, full-scale tests are paramount as for new systems, but are desirable. On this basis, the rating (SGR value) for the Tunnel Forming System could have been higher than 49. However, in our opinion, such tests should not be overloaded for any new system and therefore the system cannot be assigned a high rating without it. It appears that the Tunnel Forming System has created substantial impact in California, Florida, and other parts of USA with the exception of the East Coast.

7 EVALUATION OF THE COMPOSITE PANELIZED SYSTEMS

Structural System Description

Three products that use composite panelized technology were evaluated: the Covington, Truss-Tech, and Strickland systems. Appendix C contains product literature from all three systems. Covington and Truss-Tech are similar in that both use the basic concept of composite sandwich panels. The Covington panels have been available for a much longer time than Truss-Tech panels and were introduced with a system called "W-Panels." Truss-Tech emerged as a modification and extension of the Covington panels. The Covington panels consist of 3-in. deep, 14-gauge wire Warren trusses spaced 2 in. on centers, with preformed 2-1/4 in. thick insulative foam (expanded polystyrene) strips between each truss. The assembly is held together with 14-gauge wires welded to the trusses on 2-in. centers forming a 2 in. by 2 in. wire cage on each face of the panel. The two faces of the panels are plastered in the field by spraying plaster or gunite. Precast panels are also available in 4-ft width and 6- to 14-ft length in increments of 2 in. After plastering, the panel thickness is 4 in. or more. The panel acts as a composite structural member due to shear transfer from one skin to the other through the trussed elements.

Truss-Tech Panels are 4 ft wide and vary in length from 8 to 40 ft and in thickness from 3 to 4 in. in increments of 1 in. The panel's wire cage uses a three-dimensional steel truss for shear transfer. These panels are available in different wire gauges. The polyurethane core is placed between chord wire facings and located as required to meet structural and insulation requirements.

The Strickland System concept differs from the other two products in that it is a modular concrete forming system in which concrete is poured into metal forms, which are highly mechanized, at a precast concrete plant or casting yard. Once the concrete hardens, the inner forms are "shrunk" mechanically and removed. The precast concrete modular units are then transported to the construction site.

Information Collection

For evaluating the composite panelized systems, the following firms were contacted:

1. Covintec International, Inc.
   375 South Cactus
   Rialto, CA 92376
   Telephone: (714) 875-7263
   (800) 543-3040

2. Truss-Tech Building Systems
   10955 Hemlock Ave.
   Fontana, CA 92335
   Telephone: (714) 822-3360

These are the only two firms that manufacture and promote the two panel systems in the United States. Covintec has operations primarily in the California area as well as internationally. Truss-Tech operates in the United States only, primarily on the West Coast.

The Strickland System is manufactured and promoted by:

3. Strickland Systems, Inc.
   233 Tresca Road
   Jacksonville, FL 32211
   Telephone: (904) 725-8500

Initial information for all systems was collected by telephone. The manufacturers later sent technical manuals and other literature. Further information was gathered by field trips to Covintec International, Inc., Truss-Tech Building Systems, and Strickland Systems, Inc.

The evaluator first visited Covington and Truss-Tech in California. On December 15, 1987, the evaluator met with David Stevenson, General Manager, and Dan Jessup, Marketing Manager of Truss-Tech Structural Systems. The plant is located at Fontana, CA. The initial W-Panel system was approved in 1981 by ICBO, although no such approval exists for the Truss-Tech System (i.e., the modified covington panel). The firm has a few permanent employees and the system has one patent, with 13 more pending.

The evaluator was given an extensive tour of the plant. Various technical and nontechnical issues were discussed at length. Calculations, technical literature, names of contacts, photographs of buildings, test results and certification, detailed sketches, and other materials were given to the evaluator. In addition, buildings constructed using W-Panels were toured. No buildings using Truss-Tech Panels were under construction in the vicinity of Fontana.

The evaluator collected all information needed for an evaluation and inspected the various documents. The system can be used for civil and municipal structures other than buildings. Because of the variety of panel dimensions, it can also be used for high-rise and mid-rise apartment or office buildings. Several photographs of buildings that use the Truss-Tech System along with the names of designers, builders, and other contacts were sent to the evaluator by Mr. Stevenson after the trip.

The evaluator next met with Mr. Donald Lloyd, President of Covintec International, Inc., at his office in Rialto, CA, on December 16, 1987. The company's head office and plant are located in Rialto, with the corporate office at Fullerton and smaller offices at Sacramento and San Diego, CA. The total number of employees varies from 200 to 300. There is a large number of patents for the system in the United States and trademarks also are available in foreign countries. ICBO approval has been obtained.

The evaluator toured the large plant facilities and an onsite model building made of Covington Panels. Mr. Lloyd explained and demonstrated the operations during the manufacturing process. The evaluator also inspected a subdivision in Rialto where most homes were built using the Covington Panels. No buildings using the panels were currently under construction in the vicinity.

The evaluator obtained copies of the data required for an evaluation, including photographs of buildings and other important documents (e.g., building plans, design calculations, test results and certifications, publications). The evaluator also inspected other documents made available during the visit. Names of contacts were provided during the meeting and more names were later sent to the evaluator.

On March 9, 1988, the evaluator, accompanied by Mr. Jerry Koslowski, Vice-President of Strickland Systems, Inc., visited the Florida Mining and Materials Precast Yard at Tampa, FL. Prison cells were being cast during the visit. These cells were to be shipped to other construction sites. The evaluator took pictures of the forms and completed cells. Later, the evaluator visited two plants owned by GMF Industries at Lakeland, FL where the metal forms are manufactured. Afterward, the evaluator visited the Ramada Inn at Kissimee, FL, which was built using precast concrete modular units.

Building System Evaluation

Each system was evaluated following the evaluation procedure developed in this report. Results of the numerical evaluation are presented in Appendix D, along with the Attribute Evaluation Worksheet. The Rating Sheet is presented as Table D2. Appendix E lists points of contact.

During the early phases of evaluating the Strickland System, some facts emerged that suggested this technology may not be suitable for USACE construction, especially for Army barracks where large building modules are required. The main problem is in the logistics of transporting large units (e.g., 14 by 22 ft, 12 by 20 ft) from one location to another. Even though a casting yard could be established at the site of a large construction project, transporting and erecting the large units may still pose considerable difficulties. As such, no detailed evaluation of this system was pursued.

It is recognized that this system may have many practical merits. For example, it may be very adaptive to certain types of construction. In addition, as an industrialized system, it promises good quality control because the concrete is poured in a controlled environment. Thus, a detailed evaluation of this system may have resulted in a high SGR value. However, since it is not suitable for construction of Army barracks and residential quarters involving large modular units, a SGR value would be of little significance. USACE may wish to consider this system for other types of military construction projects where there is a better potential for success.

Results

Suitability of Building Systems for USACE Construction

The combined SGR for the remaining two Composite Panelized Systems evaluated is 45. Thus, it appears that this technology is suitable for USACE construction of residential buildings since it ranks in the "good" category (i.e., it is expected to perform better than average). However, before deciding to select one of these systems, further investigation is required to address the issues that lowered the rating from "excellent" to "good." The advantages and limitations of these systems are summarized below.

Advantages

The two panelized systems were predicted to have the following advantages:

- They are suitable for both modular and nonmodular construction and for large and small projects. Modular, large projects will be more cost-effective.

- The plaster can be textured easily.

- The strength, proportions, and dimensions of Truss-Tech panels can be varied to meet individual needs. (This is not true for the Covington Panels for which the degree of flexibility is limited.)

- The construction method is relatively easy. Even though the method is production-oriented, the skill and experience of the construction crew are not as critical. although this expertise is desirable.

- Although composite sandwich panels are used in this system, the type of construction is basically monolithic, since plaster is applied in the field. It is generally a good structural system for small buildings and is suitable for seismic zones as well.

- Integration of mechanical and electrical conduits into the systems is relatively straightforward since the plaster is applied in the field.

- There is considerable architectural freedom in configuring the building.

- The systems can be used in both residential and commercial applications.

- The systems are adaptive to prefabricated or unitized construction.

- The systems may perform well in terms of energy demand, humid environments, durability, fire-resistance, and acoustic needs; however, more substantive data are required to verify these claims.

- The maintenance cost is low.

Limitations

Composite Panelized Systems were found to have the following limitations:

- There is no adequate infrastructure for plastered construction in the United States. Although such systems have a potential market abroad, particularly in developing countries where the brick-and-plaster type of construction prevails, it may have limited acceptance here. Wood-frame construction is more common in the United States for homes and small apartment buildings; extensive plastering is unconventional. Prospective owners usually do not wish to depart from the traditional systems (i.e., wood-frame, masonry walls, and metal deck floor) unless there is enough justification for it.

- Further, since plastering is expensive, these systems are expensive with respect to wood-frame construction or even stud-and-stucco structures, although it could be economical with respect to alternatives such as concrete tilt-up construction. A detailed cost analysis would be required to establish the economic feasibility of this system more objectively.

- Conventional floor panels typically span a maximum limit of about 8 to 12 ft. Composite panels can span this distance, although a span of 12 ft for Covington Panels requires the use of reinforcing bars. Truss-Tech Panels can span considerably greater lengths with additional reinforcing and increased panel thickness. The span limitations and requirement for supporting beams may result in additional cost and loss of headroom. A combination of wood trusses and joists with composite wall panels may be economical, although this arrangement would diminish the significance of composite panelized technology as a "total system."

- These products represent a nontraditional structural system that employs a new structural concept. Therefore, great care must be exercised in designing structural details for unusual conditions.

- Modification of the building configuration is difficult once a building is constructed since the walls are permanent. It may be advisable to avoid composite wall panels where such changes are anticipated.

Summary of Findings

The evaluation results can be summarized as follows:

1. The Composite Panel Systems are suitable for residential-type, low-rise Army facilities. These systems generally conform to existing USACE criteria. They could be modified to include any new USACE criteria unless the new criteria depart drastically from the existing ones.

2. It appears that, in certain cases where modular construction is not required or desired, Composite Panelized Systems are a feasible option.

3. The Composite Panel Systems meet the general requirements of good construction practice and standards, and can be used for non-Corps construction projects as well.

4. There are some limitations for these systems that should be considered by the design professional or evaluator before making a decision about their suitability.

In general, though, regardless of the limitations discovered, these systems appear to be suitable for some types of USACE construction. Actual use of such a system will most likely depend on many considerations other than structural integrity (e.g., budget, project goals). In particular, since the cost of a structural system is important to the owner, it is recommended that a comprehensive economic analysis be conducted to compare the candidate system with other currently available structural systems.

It should be noted that, for the Composite Panelized System, no full-scale tests were conducted. While such tests are not required by codes, they are desirable for any new system. The absence of such test results for the Composite Panelized System is certainly bound to lower its overall rating.

8 CONCLUSIONS AND RECOMMENDATIONS

This report has developed a systematic method for evaluating new or innovative building technologies. This same approach could also be used to assess the performance of existing technologies (i.e., as a mechanism for system qualification).

The procedure described in this report was developed specifically for evaluating structural systems and their components. It is intended to provide a comprehensive, rational, scientific approach for investigating a single technology or for comparing two or more alternative systems to select the one best suited for military construction. While it is recognized that accurate data about building systems are difficult to obtain, this method attempts to overcome that obstacle by collecting many different kinds of information and subjecting it to both qualitative and quantitative analyses. Thus, a numerical rating system is combined with sound engineering judgment to determine a system's suitability for a given application.

The proposed method was used to evaluate two technologies that had previously been identified as promising for USACE construction (see Volume I of this report). The two technologies investigated were Tunnel Forming Systems and Composite Panelized Systems. Two tunnel forming technologies were evaluated: the Outinord System and Aarding Forms. Similarly, two composite panelized technologies were considered: Covington Panels and Truss-Tech Panels. A related product, the Strickland System, was subjected to initial evaluation but was excluded from further consideration due to logistical problems (i.e., the requirement to move very large, preformed concrete units to the construction site).

Based on the results of these evaluations, it is concluded that both Tunnel Forming Systems and Composite Panelized System meet the requirements of good construction practice in general and USACE criteria in particular. Although no comparison was intended, it can be projected that the Tunnel Forming System would have wider application and would better meet USACE's needs for residential projects involving modular construction than would Composite Panelized Systems. When modular construction is not required or desired, the Composite Panelized System can be expected to be the superior option.

A major advantage of the Tunnel Forming System is the speed of construction it permits, which is important for large construction projects. The primary disadvantage is that it is not economical for small projects.

The main advantage of Composite Panelized Systems is that they are suitable for both modular and nonmodular construction and for large and small projects (although large, modular structures would probably be more cost-effective). A major limitation to these systems is the lack of a mature construction market for plastered construction in the United States. An additional drawback is the limited span possible with the panels. However, with further development and testing, this problem could be overcome for barrack-type construction if the product could be customized to meet the span requirements.

The investigation described in this report has shown that the proposed evaluation method can be used successfully to select technologies for USACE construction. It is important to recognize that any product or system being considered for use in military construction must be scrutinized as usual through engineering and economic analyses based on the project mission and site-specific conditions. The entire BTFE cycle (including the evaluation process) is intended as an organized method to help decision-makers screen new or innovative technologies with potential application to USACE. The primary goal is to ensure that USACE is using state-of-the-art products and systems that provide the best quality facilities at the lowest possible cost.

It is recommended that USACE adopt the BTFE cycle as a standard approach to identifying and evaluating building technologies. In addition, it is recommended that the procedures be further enhanced through the development of technology data bases and decision-support software.

METRIC CONVERSION TABLE

1 in.	=	2.54 cm
1 ft	=	0.305 m
1 sq ft	=	0.092 m^2

CITED REFERENCES

Napier, T., and M. Golish, *A System Approach to Military Construction*, Technical Report P-132 ADA123382 (U.S. Army Construction Engineering Research Laboratory, November 1982).

Rosen, H. J., and P. M. Bennet, *Construction Materials Evaluation and Selection: A Systematic Approach* (John Wiley & Sons, 1979).

UNCITED REFERENCES

American National Standards Institute, *Minimum Design Loads for Buildings and Other Structures* (1982).

Blockley, D. I., *The Nature of Structural Design and Safety* (John Wiley & Sons, 1980).

Building Officials and Code Administrators International, Inc., *The BOCA Basic Building Code* (1978).

Howard, H., Structure, *An Architects Approach* (McGraw-Hill 1966).

Institute of Civil Engineers, *Safe Construction for the Future* (1980).

International Conference of Building Officials, Uniform Building Code (1985).

Janney, J. R., *Guide to Investigation of Structural Failures* (American Society of Civil Engineers, 1986).

King, R. W., and R. Hudson, *Construction Hazard and Safety Handbook* (Butterworth, 1985).

Levitt, R. E., and N. M. Samelson, *Construction Safety Management* (McGraw-Hill, 1987).

MacGregor, J. G., "The Structural Design Process," presented at the International Association for Bridge and Structural Engineering 12th Congress, Vancouver, B.C. Introductory Report (1984).

Mainstone, R., *Developments in Structural Form* (MIT Press, 1975).

McKaig, T. H., *Building Failures* (McGraw-Hill, 1962).

O'Brien, J. J., *Value Analysis in Design and Construction* ((McGraw-Hill, 1976).

Pugsley, A., *The Safety of Structures* (Edward Arnold Ltd., London, 1966).

Ratay, R. T. (Ed.), *Temporary Structures in Construction Operations* (American Society of Civil Engineers, 1987).

Schaeffer, P. E. *Building Structures: Elementary Analysis and Design* (Prentice-Hall, 1980).

Simpson, J. W., and P. J. Horrobin, *The Weathering and Performance of Building Materials* (Wiley-Interscience, 1970).

Sinnot, R., *Safety and Security in Building Design* (Collins Professional and Technical Books, London, 1985).

Underwriters Laboratories, Inc., *Fire Resistance Directory* (1986).

APPENDIX A:

BUILDING STANDARDS/CODES USED IN THE EVALUATION

This appendix lists the various standards and codes considered in the building technology evaluation. In addition, it contains the tables developed from the performance criteria identified. Table A1 was explained adequately in the text. Table A2 was not discussed in detail and merits further explanation here.

USACE, DA, and DOD regulations were reviewed for performance criteria relating to the identified structural system attributes. While no list of performance criteria can be complete because performance expectations depend on specific goals and situations. Table A2 reflects the *general* expectations for structural system performance. Only information that could be retrieved from the documents and that relates to the evaluation is included in Table A2. This table can be expanded as new information becomes available.

Performance criteria are listed according to structural system attribute, material, and structural component. Abbreviations for references, attribute and material codes, and regulations reviewed are listed below. The documents reviewed also are listed in the *Federal Construction Regulations Service* Index, March-April 1987.

Material Codes

0 General

1 Steel

1A Steel, Light Gauge

2 Concrete, Cast-in-Place

2A Concrete, Precast/Prestressed

2B Concrete, Composite With Metal Deck

2C Concrete, Thin-Shelled

3 Aluminum

4 Masonry

5 Timber

6 Structural Metals (Steel or Aluminum)

7 Required Coatings

8 Cement Plaster

9 Reinforcing Steel

9A Concrete Reinforcement

9B Masonry Reinforcement

9C Welded Wire Fabric (WWF) and Other Miscellaneous Reinforcing Material

Federal Construction Regulations Referenced in Table A2

Department of Defense

DOD 4270.1-M

Department of the Army

Technical Manuals.

TM 5-809-1	Load Assumptions for Buildings
TM 5-809-3	Masonry Structural Design for Buildings
TM 5-809-4	Steel and Aluminum Structural Design for Buildings
TM 5-809-9	Structural Design for Thin-Shell Roof Construction
TM 5-809-10	Seismic Design for Buildings
TM 5-809-11	Design Criteria for Facilities in Areas Subject to Typhoons and Hurricanes
TM 5-853-1	Designing for Security
TM 5-1300	Structures to Resist the Effects of Accidental Explosions

U.S. Army Corps of Engineers

[AEI-DC]	Architectural and Engineering Instructions - Design Criteria
6.6	Glue Laminated Structural Timber
CE-R-03.1	Concrete
CE-R-04.1	Masonry
CE-R-04.2	Reinforced Masonry
CE-R-05.2	Steel Roof Deck
CE-R-15.7	Sprinkler Systems, Fire Protection

Guide Specifications.

CEGS-03300	Concrete for Building Construction
CEGS-03301	Concrete for Building Construction (Minor Requirements)
CEGS-03330	Cast-in-Place Architectural Concrete
CEGS-03410	Precast Concrete Floor and Roof Units
CEGS-03414	Precast Roof Decking
CEGS-03510	Roof Decking, Cast-in-Place Lightweight
CEGS-04200	Masonry
CEGS 04230	Reinforced Masonry
CEGS-05061	Ultrasonic Inspection of Weldments
CEGS-05120	Structural Steel
CEGS-05311	Steel Roof Deck
CEGS-07265	Spray Applied Fireproofing

CEGS-09200	Lathing and Plastering
CEGS-13120	Metal Buildings
CW-03101	Formwork for Concrete
CW-03150	Expansion, Contraction and Construction Joints in Concrete
CW-03210	Steel Bars, Welded Steel Wire Fabric and Accessories for Concrete Reinforcement
CW-03230	Stressing Tendons and Accessories for Prestressed Concrete
CW-03301	Cast-in-Place Structural Concrete
CW-03425	Precast Prestressed Concrete
CW-05501	Metalwork Fabrication, Machine Work and Miscellaneous Provisions

Engineer Manuals.

EM 385-1-1	Safety and Health Requirements Manual
EM 1110-1-2101	Working Stresses for Structural Design
EM 1110-2-2000	Standard Practice for Concrete

Engineer Pamphlets.

EP 385-1-30	Scaffolds Safe Operating Procedures
EP 385-1-34	Placement of Precast Concrete Panels Safe Operating Procedures
EP 385-1-50	Steel Reinforcing of Concrete Safe Operating Procedures

Engineer Regulations.

ER 1110-345-100	Design Policy for Military Construction
ER 1110-345-700	Design Analyses

Engineer Technical Letter.

ETL 1110-3-328	Computer Program CBARCS for Designing Structures to Resist the Effects of Accidental Explosions
ETL 1110-3-340	Fire Protection Criteria
MOGS-03302	Concrete
MOGS-05121	Structural Steel

Abbreviations for Codes/Standards Referenced in Table A2

ACI SP4	American Concrete Institute, "Formwork for Concrete"
ACI SP-66	American Concrete Institute, "ACI Detailing Manual - 1980"
ACI 214	American Concrete Institute, "Recommended Practice for Evaluation of Strength Test Results of Concrete"
ACI 301	American Concrete Institute, "Structural Concrete for Buildings"
ACI 315	American Concrete Institute, "Manual of Standard Practice for Detailing Reinforced Concrete Structures"

ACI 318	American Concrete Institute, "Building Code Requirements for Reinforced Concrete"
ACI 347-78	American Concrete Institute, "Recommended Practice for Concrete Formwork," Publication ACI 347-78
ACI 523.3R	American Concrete Institute, "Guide for Cellular Concretes Above 50 pcf, and for Aggregate Concretes Above 50 pcf with Compressive Strengths Less Than 2500 psi," Publication 523.3R-75 (Rev. 1982)
AISC	American Institute of Steel Construction, "Specification and Erection of Structural Steel for Buildings"
AISC-JTS	American Institute of Steel Construction "Specification for Structural Joints Using ASTM A325 or A490 Bolts" (August 14, 1980)
AISI	American Iron and Steel Institute, "Specifications for the Design of Cold-Formed Steel Structural Members"
AITC	American Institute of Timber Construction, "Timber Construction Standards"
ALUM	The Aluminum Association, "Specifications for Aluminum Structures"
ANSI-A10.9	American National Standards Institute, "Safety Requirements for Concrete Construction and Masonry Work," ANSI A10.9
ANSI B46.1	American National Standards Institute, "Surface Texture (Surface-Roughness, Waviness, and Lay)," Publication B46.1-1978
ANSI-PW	American National Standards Institute, "Plain Washers," Publication B18.22.1-1965 (Rev. 1981)
ANSI-RM	American National Standards Institute, "American Standard Building Code Requirements for Reinforced Masonry"
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, *Handbook, Fundamentals* (1985 and Errata)
ASNT	American Society for Nondestructive Testing, "Personnel Qualification and Certification in Non-destructive Testing" (August 1984), Supplement C - "Ultrasonic Testing Method" (1980), Publication SNT-TC-1A
ASTM A 6	American Society for Testing and Materials, "General Requirements for Rolled Steel Plates, Shapes, Sheet Piling and Bars for Structural Use"
AWS	American Welding Society, "Structural Welding Code - Steel," Publication D1.1-86
AWS D1.4	American Welding Society, "Structural Welding Code - Reinforcing Steel"
AWS-WBC	American Welding Society, "Code for Welding in Building Construction"

BIA	Brick Institute of America, "Recommended Building Code Requirements for Engineered Brick Masonry"
CRD	U.S. Army Corps of Engineers, *U.S. Army Corps of Engineers Handbook for Cement and Concrete*
IASS	International Association for Shell and Spatial Structures, "Recommendations for Reinforced Concrete Shells and Folded Plates," Medwadoski, S. J., Working Group No. 5, Madrid, 1979
MIL-STD-271E	Military Standards, "Nondestructive Testing Requirements for Metals," MIL-STD-271E & Notice 1
MIL-STD-410D	Military Standards, "Nondestructive Testing Personnel Qualification and Certification (Eddy Current, Liquid Penetrant, Magnetic Particle, Radiographic and Ultrasonic)"
NCMA	National Concrete Masonry Association, "Specifications for the Design and Construction of Load Bearing Concrete Masonry"
NFOPA	National Forest Products Association, "National Design Specifications for Stress Grade Lumber and Its Fastenings"
NLMA	National Lumber Manufacturers Association, "National Design Specifications for Stress Grade Lumber and Its Fastenings"
PCI-PPC	Prestressed Concrete Institute, *PCI Design Handbook-Precast Prestressed Concrete* (MNL 120)
PCI-QC	Prestressed Concrete Institute, *Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products*, MNL 116
SCPI	Structural Clay Products Institute, "Building Code Requirements for Engineered Brick Masonry"
SDI	Steel Deck Institute, *SDI Design Manual for Composite Decks, Form Decks, and Roof Decks*, 1984
SJI	Steel Joist Institute, "Standard Specifications and Load Tables, Open Web Steel Joists and Longspan Steel Joists," and a similar publication covering deep longspan steel joists.
UBC	International Conference of Building Officials, *Uniform Building Code*, 1985

Table A1

Statement of Specific Performance Requirements

Major Attributes of Structural System & Components	Specific Attribute of Performance Requirements		Structural Component Affected	Required Test (#*)	Code/Standards Section No. UBC	BOCA	Remarks
1. Structural Safety							
Design:	1.1	Overloads	Foundations, Substructure Superstructure	2	2303 (e)	701.1, 716.1	
	1.2	Collapse Safety/ Ultimate Strength	Superstructure	2, 3, 4	2303 (e) 2312, 2721	701, 702, 1802-1807	Specific require-ments for different materials
Construction:	1.3	Formwork/Temporary Supports	Substructure: Basement/ Foundation Walls; Superstructure: Floor, Roof, Stairs, Bearing Walls, Columns, Tension Members	1, 2, 5	2606 (a), (b) 2517 (d), (g)	800.1 - App. B, 1307.1, 1314	
	1.4	Construction Hazards	Substructure: Basement/ Foundations Walls; Superstructure	1, 5		1300-1306	
	1.5	Changing Structure During Erection and Construction	Substructure: Basement/ Foundation Walls; Superstructure	1, 2, 5	2606 (b), (d) 2720	836	
	1.6	Material Handling & Quality Control	Foundations, Substructure,	1, 5	Ch. 24-28	Art. 8	
Occupancy:	1.7	Strength Against Overloads	Foundations, Substructure, Superstructure	2, 5	2303 (e)	701.1	
	1.8	Stability	Superstructure: Beams/ Girders/Lintels, Trusses/ Joists, Beams/Girders/ Purlins/Rafters/Lintels, Trusses/Joists, Bearing Walls/ Shear Walls, Columns	2, 5	2303 (b), 2705, 2721 (c), (d)	2411	Ensured by design
	1.9	Collapse Mode	Superstructure	2			Ensured by design & test

*All tests listed are required.

Table A1 (Cont'd)

Major Attributes of Structural System & Components	Specific Attribute or Performance Requirements	Structural Component Affected	Required Test (P*)	Code/Standards Section No. UBC	Code/Standards Section No. BOCA	Remarks
	1.10 Fracture	Superstructure: Special Elements	2, 3			Ensured by ASTM tests; design approach not well established
	1.11 Fatigue	Superstructure	2, 3			Ensured by ASTM test; AISC, ACI, etc.
	1.12 Accidental/Special Loads	Substructure: Basement/ Foundation Walls; Superstructure	2		708, 709	
	1.13 Progressive Failure	Superstructure	2, 5		701.2	
2. Structural Serviceability						
Design & Occupancy:	2.1 Loads & Load Combinations	Foundations, Substructure, Superstructure	2	2303-2306	704-706, 710-714, 717, 718	
	2.2 Strength Properties	Foundations, Substructure, Superstructure Superstructure	2, 4	2603	Art. 8 Parts A & B,	See AISC, ACI, etc.
	2.3 Stiffness/Vibrations	Substructure: Basement/ Foundation Walls; Superstructure: Bearing Walls/Shear Walls, Columns	2, 3, 4, 5 2, 3, 4, 5	2703, 2609 (f), 2710, 2307 2703, 2609 (f) 2710, 2307	702.2 803.3 702.2 803.3	
	2.4 Strength to Support Loads	Foundations, Substructure, Superstructure	2, 4	2802(a), 2303(d), 2504, 2406-2409 2622 (d), 2702, 2509, 2511	719	
	2.5 Stable Equilibrium/ Lateral Bracing	Superstructure	2	2610 (e), 2506(h), 2517 (d), (g)	836	
	2.6 Roof Ponding	Superstructure: Roof	2	2710 (b)	710.4	

Table A1 (Cont'd)

Major Attributes of Structural System & Components	Specific Attribute or Performance Requirements	Structural Component Affected	Required Test (P*)	Code/Standards Section No. UBC	BOCA	Remarks
3. Fire Safety						
Design, Construction & Occupancy:	3.1 Combustibility	Superstructure	3		911 903.5 834.4	
	3.2 Flame Spread & Potential Heat	Superstructure	1, 3	Ch 42	904, 905, 911	
	3.3 Fire Resistance & Endurance	Superstructure	1, 3	4303-4305 505 (e)	Table 214 911	
	3.4 Strength Maintenance	Superstructure	1, 2, 5			
	3.5 Collapse Safety	Superstructure	1, 2			
	3.6 Protective Devices	Superstructure	1, 5	2516 (f) 508	1200	
	3.7 Smoke Propagation/ Toxicity	Superstructure	1, 3, 5			
4. Habitability						
Occupancy:	4.1 Water Penetration/ Permeability	Substructure: Basement/ Foundations Walls; Superstructure: Roof, Exterior Walls	1, 5	1707	872	Assess potential for compliance and value as integrated system
	4.2 Acoustic Environment	Superstructure: Floor Diaphragm/Sheathing/ Slab, Exterior Walls, Interior Walls	1, 3, 4, 5	Appendix Ch 35	522.3	
	4.3 Thermal Properties/ Freeze-Thaw Exposure	Substructure: Basement/ Foundation Walls; Superstructure: Roof, Exterior Walls, Special Elements	1, 3, 5	1705 (g), Appendix Ch 53	87[illegible]	e.g., fill material
	4.4 Health, Comfort, Light, & Ventilation	Superstructure: Floors, Roof, Stairs, and Bearing Walls/Shear Walls	1, 4, 5			[illegible]

Table A1 (Cont'd)

Major Attributes of Structural System & Components	Specific Attribute or Performance Requirements		Structural Component Affected	Required Test (P*)	Code/Standards Section No. UBC	BOCA	Remarks
	4.5	General Safety	Superstructure	1, 2			Assess potential influence on safety systems
5. Durability							
Occupancy:	5.1	**Mechanical Properties**	**Substructure, Superstructure**	1, 3			
	5.2	**Wear Resistance**	**Substructure, Superstructure**	3			
	5.3	**Dimensional Stability**	**Substructure, Superstructure**	1, 3, 5			
	5.4	**Weathering**	**Superstructure: Roof, Exterior Walls**	3	1707	872	
	5.5	**Rheological Properties**	**Substructure, Superstructure**	2, 3			
	5.6	**Environmental Effects**	**Superstructure: Roof, Exterior Walls**	3, 5	2516 (c)	834.3 873, 874	
	5.7	**Corrosion Resistance**	**Foundations, Substructure, Superstructure**	3	827.3	826.6	
6. Constructibility							
Design:	6.1	Structural Planning	Superstructure	1			Assess potential ease of planning, design, & analysis
	6.2	Susceptibility to Structural Analysis	Foundations, Substructure, Superstructure	2			
	6.3	Ease of Detailing	Substructure, Superstructure,	1, 2			
Construction:	6.4	Material Availability	Foundations, Substructure, Superstructure	1, 5			Assess potential ease of construction
	6.5	Availability of Skilled Labor & Equipment	Foundations, Substructure, Superstructure	1, 5			

Table A1 (Cont'd)

Major Attributes of Structural System & Components	Specific Attribute or Performance Requirements	Structural Component Affected	Required Test (P*)	Code/Standards Section No. UBC	BOCA	Remarks
	6.6 Ease of Erection	Superstructure	1, 2, 5 and Coordination			
	6.7 Adaptability to Prefabrication and Unitized Construction	Superstructure	1, 2, 5			
	6.8 Required Precision & Tolerance/Quality Control	Superstructure	1, 4, 5			
	6.9 Ease of Material Handling	Foundations, Substructure, Superstructure	1, 2, 5			
	6.10 Reuse of Temporary	Substructure, Superstructure,	1, 5,			
7. Maintainability						
Occupancy:	7.1 Material Resistance to Deterioration	Substructure, Superstructure,	1, 5			
	7.2 Susceptibility to Cracking	Substructure; Superstructure: Floors, Roof, Stairs, Bearing Walls/Shear Walls, Tension Members	3, 5			Sensitivity to Temperature and Humidity Variation
	7.3 Resistance to Chemical	Substructure, Superstructure,	3			i.e., environmental chemical elements/pollutants
	7.4 Repairability	Substructure, Superstructure,	1, 4, 5			Bondable to other materials?
	7.5 Ease of Periodic	Superstructure Inspection	1, 4, 5			e.g., exposure risk, connection placement
	7.6 Potential for Remodeling	Superstructure: Floors, Roof, Stairs, Bearing Walls/Shear Walls, Columns, Connections/Joints	1, 2, 5			Monolithic vs. components

Table A1 (Cont'd)

Major Attributes of Structural System & Components	Specific Attribute or Performance Requirements	Structural Component Affected	Required Test (P*)	Code/Standards Section No. UBC	BOCA	Remarks
8. Architectural Function						
Design & Occupancy:						
	8.1 Building Form and Scale	Superstructure	1			Assess economic size range, relate to human spatial needs
	8.2 Span and Size Limits of Components	Superstructure: Floors, Bearing Walls/Shear Walls	1			Assess span/depth ratio, wall thicknes: req'd., relate to human spatial needs
	8.3 Interior Space Definition, Subdivision & Separation	Superstructure: Floors, Stairs, Interior Walls, Bracing Elements	1			Assess economic floor area range, economic floor-to floor height. Relate to human spatial needs
	8.4 Building Enclosure	Superstructure: Exterior Walls, Bracing Elements	1			
9. Economy						
Design & Construction	9.1 Material	Foundations, Substructure, Superstructure	1, 3			
	9.2 Labor	Foundations, Substructure, Superstructure	1, 5			
	9.3 Equipment	Foundations, Substructure, Superstructure	1, 5			
	9.4 Design Modifiability During Construction	Foundations, Substructure, Superstructure	1, 5			
	9.5 Construction Speed	Foundations, Substructure, Superstructure	1, 5			
Occupancy:	9.6 Maintenance and Management	Superstructure	1, 5			

Table A1 (Cont'd)

Major Attributes of Structural System & Components	Specific Attribute or Performance Requirements	Structural Component Affected	Required Test (P*)	Code/Standards Section No. UBC	Code/Standards Section No. BOCA	Remarks
10. Compatibility						
Design & Occupancy:	10.1 Analysis of Connections	Superstructure: Connections/Joints	1, 2, 3	5004, 2802 2712, 2714 2510, 2516 (j), 2624, 2721 (i)	826.5	
	10.2 Connection Detailing and Simplicity	Superstructure: Connections/Joints, Special Elements	1	2803	826.5	
	10.3 Joining Materials Interaction	Substructure, Superstructure	1, 4, 5	2510 (h) 2503 (d) 2804 (c), (d)	826.5	
	10.4 Ability to Receive and Retain Coatings	Superstructure	3, 4, 5		826.5	
11. System Integration						
Design, Construction and Occupancy:	11.1 Architectural Design	Superstructure	1			Assess ease of interface to other systems and general requirement for other systems in order to provide liveable buildings
	11.2 Power and Lighting	Superstructure	1, 5			
	11.3 Temperature Control	Substructure, Structure	1, 2			
	11.4 **HVAC**	Substructure, Structure	1, 2, 5			
	11.5 Mechanical/Engineering Enlargement During Occupancy	Substructure, Superstructure	1, 4, 5			
	11.6 Water Supply & Plumbing	Substructure, Superstructure	1, 2, 5			
	11.7 Foundation System	Foundations, Substructure	1, 2			
	11.8 Security System	Superstructure	1, 5			

Table A1 (Cont'd)

Major Attributes of	Specific Attribute or Performance	Structural Component	Required Test (P*)	Code/Standard Section No. *UBC	Code/Standard Section No. BOCA	Remarks
12. Code Compliance						
Design, Construction and Occupancy:	12.1 Review of Code	Foundations, Substructure, Superstructure	1, 2, 3			
	12.2 Satisfaction of Specific Requirements	Foundations, Substructure, Superstructure	1, 2, 3, 5	2303 Ch 50 Appendix Ch 55	835 837-856 1800, 2000	

Table A2

Reference to USACE/DA/DOD Regulations

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
1.1 Overloads*	General	Foundations, Substructure, Superstructure		x		TM 5-809-11	Design for specified wind velocity	Areas subject to typhoons & hurricane
	Steel	Substructure, Superstructure		x		TM 5-809-1/ AFM 88-3 Ch 1, TM 5-809-10 NAVFAC P-355/ AFM 88-3 Ch 13	Compliance to reference or careful analysis of design loads in accordance with technical literature	
		Superstructure: Beams/ Girders/Lintels, Trusses/ Joists, Beams/Girders/ Purlins/Rafters/Lintels, Trusses/Joists		x		TM 5-809-11	Corrosion protection is likely to be exposed to storm water	Areas subject to typhoons & hurricane
		Substructure, Superstructure	x			[AEI-DC] Ch8	[AISC]	Stress allowances, design methods
		Substructure, Superstructure			x	DOD 4270.1M Ch 6	[AISC]	Stress allowances, design methods
		Substructure, Superstructure	x			CEGS-05120 Par 2	[AISC] [AWS] [AISC-JTS]	
		Superstructure: Floor Trusses/Joists, Roof Trusses/Joists	x			[AEI-DC]	[SJI]	Stress allowances, design methods
		Substructure, Superstructure		x		TM 5-809-4	Compliance [AISC]	
	Steel, Light-Gauge	Superstructure	x			[AEI-DC] Ch 8	[AISI]	Stress allowances, design methods
		Superstructure	x			DOD 4270.1-M Ch 6	[AISI]	Stress allowances, design methods
		Superstructure			x	TM 5-809-4	[AISI], compliance	

*Note: See Table 1 for complete list of major and specific attributes.

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
1.1 (cont'd)	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			[AEI-DC] Ch 8	[ACI-318]	Stress allowances, design methods
		Foundations, Substructure, Superstructure			x	DOD 4270.1-M Ch 6	[ACI-318]	Stress allowances, design methods
	Concrete, Precast/ Prestressed	Superstructure	x			CW-03425 [PCI-PPC]	[ACI 318]	
	Aluminum	Substructure, Superstructure		x		TM 5-809-1/ AFM 88-3 Ch 1, TM 5-809-10/ NAVFAC P-355 AFM 88-3 Ch 13	Compliance to reference or careful analysis of design loads in accordance with technical literature	
		Substructure, Superstructure	x			[AEI-DC] Ch 8	[ALUM]	Stress allowances, design methods
		Substructure, Superstructure			x	DOD 4270.1-M Ch 6	[ALUM]	Stress allowances, design methods
	Masonry	Substructure: Basement/ Foundation Walls; Superstructure			x	DOD 4270.1-M Ch 6	[ANSI-RM] [BIA] [NCMA]	Stress allowances, design methods
		Substructure: Basement/ Foundations Walls; Superstructure	x			[AEI-DC] Ch 8	[ANSI-RM] [BIA] [NCMA]	Stress allowances, design methods
		Superstructure			x	TM 5-809-3	NCMA Tek Notes Tek 30, Tek 24	Reinforced masonry columns
		Superstructure: Columns			x	TM 5-809-3	NCMA Tek Notes Tek 30, Tek 24	Nonreinforced masonry columns
	Timber	Superstructure	x			Ch 8	[AEI-DC]	[NFOPA] Design methods
		Superstructure			x	DOD 4270.1-M Ch 6	[NFOPA]	Stress allowances, design methods
1.2 Collapse Safety/ Ultimate Strength	Steel	Superstructure	x			Ch 8	[AEI-DC]	[AISC] Design methods
		Superstructure			x	DOD 4270.1-M Ch 6	[AISC]	Design methods

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
1.2 (cont'd)		Superstructure	x			CEGS-05120 Par 2	[AISC] [AWS] [AISC-JTS]	
		Superstructure			x	TM 5-809-4	Compliance [AISC]	
		Superstructure: Floor Trusses/Joists, Roof Trusses/Joists	x			TM 5-809-4	Compliance [SJI]	
	Steel, Light-Gauge	Superstructure	x			[AEI-DC]	[AISI] Ch 8	Design methods
		Superstructure			x	DOD 4270.1-M Ch 6	[AISI]	Design methods
		Superstructure: Roof Diaphragm/Sheathing/Slab	x			CEGS-03510 for CIP	[AISI]	Steel forms LTWT CCI
	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			[AEI-DC] Ch 8	[ACI-318]	Design methods
		Foundations, Substructure, Superstructure	x			DOD 4270.1-M Ch 6	[ACI-318]	Design methods
	Concrete, Cast-in-Place	Superstructure	x			CW-03425	[ACI 318] [PCI-PPC]	
		Superstructure: Roof Diaphragm/Sheating Slab	x			CEGS-03414 Par 3	[ACI 318] [ACI 523]	[AISC] where applicable
	Concrete, Thin-Shelled	Roof	x			TM 5-809-9 [IASS]	[ACI 318], Ch. 19 accordance	Design in to code requirements
	Aluminum	Superstructure			x	DOD 4270.1-M Ch 6	[ALUM]	Design methods
				x		[AEI-DC] Ch 8	[ALUM]	Design methods
	Masonry	Substructure: Basement/ Foundation Walls; Superstructure	x			[AEI-DC] Ch 8	[ANSI-RM] [BIA] [NCMA]	Design methods
		Substructure: Basement/ Foundation Walls; Superstructure			x	DOD 4270.1-M	[ANSI-RM] [BIA] [NCMA]	Design methods
		Superstructure: Columns		x		TM 5-809-3 masonry columns	NCMA Tek Notes Tek 30, Tek 24	Reinforced

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
1.2 (cont'd)		Superstructure: Columns	x			TM 5-809-3	NCMA Tek Notes, Tek 30, Tek 24	Nonreinforced masonry columns
	Timber	Superstructure	x			[AEI-DC] Ch 8	[NFOPA]	Design methods
		Superstructure			x	DOD 4270.1-M Ch 6	[NFOPA]	Design methods
1.3 Formwork/ Temporary Supports	General	Superstructure: Special Elements	x			EM 385-1-1 Sec 22	EM 1110-1-2101	Temporary supports
		Superstructure: Elements	x	EM 385-1-1 Sec 22.A.01		1500 fiber (stress grade) construction grade lumber for all load carrying timber members of scaffold framing		Scaffolds
		Superstructure: Special Elements	x	EM 385-1-1 Sec 22.A.13		Permissible span tables		Scaffold flooring
		Superstructure: Special	x	EM 385-1-1 Sec 29.A.01		[ACI 347-78] [ANSI A10.9] Compliance w/Section 29		Formwork & falsework
	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x	CW-03101 Sec 9.3		Tunnel lining bulkhead forms shall not be removec in less than 12 hours and tunnel lining forms in not less than 16 hours		
	Concrete, in-Place	Foundations, Substructure, Superstructure	x	CEGS-03300 Par. 10, Technical Note U.		[ACI 301]		Where tolerances are needed
	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x	CW-03101 Sec 4		[ACI 347]		
	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x	CW-03101 Sec 4		For class A or class F finish, deflection of facing material between studs as well as deflection of studs and walers = 0.0025 times the span		Design of form work

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
1.3 (cont'd)	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			CW-03101 Sec 9.1	Formwork for unsupported concrete shall not be removed in less than 24 hours	
						CW-03101 Sec 9.2	Formwork for supported concrete shall not be removed in less than four days.	ASTM Tests
	Concrete, Cast-in Place	Substructure, Superstructure	x			CEGS 03300 Sec 10	Compliance	
		Substructure, Superstructure	x			EM 1110-2-2000 Sec 7-10	Compliance	
		Substructure, Superstructure	x			EM 385-1-1 Sec 22 Sec 29 App. P	ACI 347-78 ANSI A10.9 A10.8 EM 1110-1-2101	
		Superstructure: Floor Diaphragm/Sheathing/Slab, Roof Diaphragm/Sheathing/Slab	x			CEGS 03330 Sec 6	$\leq$1/360	Formwork deflections for architectural concrete
		Superstructure: Special Elements	x			EM 385-1-1	Compliance w/Section 22	Ramps, runways, platforms, scaffolds, & towers
		Superstructure: Special Elements	x			EP 385-1-30	(ANSI.8) Compliance w/reference	Design
1.4 Construction Hazards	Concrete, Cast-in Place	Superstructure: Stairs	x			EP 385-1-50	Conformance to reference	Steel reinforcement
	Concrete, Precast/	Superstructure: Bearing Walls/Shear Walls Prestressed	x			EP 385-1-34	Conformance to reference	P C [illegible] design & placement
1.5 Changing Structure During Erection and Construction	General	Foundations, Substructure, Superstructure	x			EM 385-1-1	Conformance	
	Concrete, Cast-in Place	Foundations, Substructure, Superstructure	x			EM 1110-2-2000 Sections 6-6, 7-4, 7-5, 7-6, 7-7, 7-8, 7-9, Appendix C	Conformance safety procedures, finishing procedures	Placement

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
1.5 (cont'd)	Concrete, Precast/ Pres-stressed	Superstructure: Floor Diaphragm/Sheathing/Slab, Roof Diaphragm/Sheating/Slab	x			CEGS 03410 Sec 7	Conformance with *manufacturers' recommendations*	
1.6 Material Handling & Quality Control	Steel	Substructure, Superstructure	x			MOGS-05121 Sec 2	[AWS] [AISC-JTS]	Welding and high-strength bolting
	Steel	Substructure, Superstructure	x			CW-05501 Sec 8, 9	[AWS] ASTM Tests (inspection procedures)	
	Concrete, Cast-in-Place	Substructure, Superstructure	x			CEGS-03300 Sec 6.1-6.5	ASTM Tests	
	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			CEGS-03300 Sec 11	[AWS D1.4]	Reinforcement welding
	Concrete, Cast-in Place	Superstructure: Floor Diaphragm/Sheathing/Slab	x			CEGS-03300 Sec 21	Finished surfaces plane, with no deviation greater than 1/8 inch when tested with a 10-foot straight edge	
	Concrete, Cast-in Place	Foundations, Substructure, Superstructure	x			CW-03301	Sec 7.6, ASTM Tests	Average strength
							Sec 11	Placement procedures
							Sec 12	Finish
							Sec 13	Curing & protection
	Concrete,	Superstructure Cast-in-Place	x			CW-03301	ASTM Tests CRD Standards	Shotcrete
	Concrete, Cast-in-Place	Substructure,	x			CEGS-03300	Conformance	
		Superstructure, Substructure	x			CEGS-03300	Conformance	Lightweight concrete
		Substructure: Slab-on-Grade Basement/Foundation Walls	x			CEGS-03301	[ACI 318-83] [SP-86] [ASTM C94-86]	

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
1.6 (cont'd)	Foundations,	Substructure, Superstructure	x			EM 1110-2-2000 Sections 6-1, 6-2, 7-2, 7-3	Conformance procedures	Testing
		Superstructure: Roof Diaphragm/Sheathing/Slab	x			CEGS-03510	Conformance; for steel forms, follow [AISI] and ≤ 1/240 of clear span under design live load	Forms, testing, placement, mix, curing for lightweight concrete
	Concrete, Precast/ Prestressed	Superstructure	x			CW-03230	ASTM Tests CRD Standards [ACI 315] [ACI 318]	
	Concrete, Precast/ Pre-stressed	Superstructure: Floor Diaphragm/Sheathing/Slab, Roof Diaphragm/Sheathing/Slab	x			CEGS-03410	[ACI 318-83] [PCI MNL 116-77]	
		Superstructure: Roof Diaphragm/Sheathing/Slab				CEGS-03414	ASTM Tests [ACI 318] [AISC]	Spans <8 ft
	Concrete, Precast/ Prestressed	Superstructure				CW-03425 Sec 4 Sec 9 Sec 19	ASTM Tests [PCI-QC]	
	Masonry	Superstructure: Bearing Walls/Shear Walls	x			CE-R-04.1	ASTM Tests	
	Masonry	Superstructure: Bearing Walls/Shear Walls	x			CE-R-04.2	ASTM Tests	Reinforced masonry
	Masonry	Superstructure: Bearing Walls/Shear Walls		x		TM 5-809-3	Tabular Values	
	Masonry	Substructure: Basement/ Foundation Walls; Superstructure	x			CEGS-04230	Conformance	Reinforced masonry
		Substructure: Basement/ Foundation Walls; Superstructure	x			CEGS-04200	Conformance	
	Timber	Superstructure	x			6.6 Section 3, 6	ANSI A190.1 AITC 111 AWPA C1, C2 or VWI Spec or NWMA 1.5.4	

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
1.6 (cont'd)								
	Structural Metals Steel or Aluminum)	Superstructure: Connections/Joints	x			CEGS-05061	Conformance to specific requirements	Acceptance/ rejection requirements for weldments (ultrasonic inspection)
	Reinforcing Steel	Foundations, Substructure, Superstructure	x			CW-03210 Sec 6, 7	ASTM Tests, except as discussed in Section 6 [ACI 315] [ACI 318] [AWS D1.4]	
	Concrete Reinforcement	Substructure, Superstructure	x			CEGS-03300 Sec 6.10, Technical Note K	ASTM Tests	
1.7 Strength Against Overloads	General	Foundations, Substructure, Superstructure		x		TM 5-809-10 NAVFAC P-355 AFM 88-3 Ch 13 Sections 8-2, 66	Conformance	
						TM 5-809-10 NAVFAC P-355.1 AFM 88-3 Ch 13 Sec A, 8-3	Conformance	
	Concrete, Cast-in Place	Foundations, Substructure, Superstructure	x			CEGS-03300 Section 7	Conformance	
		Foundations, Substructure, Superstructure	x			EM 1110-2-2000 Section 3-2	Conformance	
	Concrete, Precast/ Prestressed	Superstructure: Floor Diaphragm/Sheathing/Slab, Roof Diaphragm/Sheathing/Slab	x			CEGS-03410 Section 6	[ACI 318]	
		Foundations, Substructure, Superstructure	x			EM 1110-2-2000 Section 3-3	Conformance	Concrete mix proportioning
1.9 Collapse Mode	General	Substructure, Superstructure		x		TM 5-809-10 NAVFAC P-355 AFM 88-3 Ch 13	"Resist collapse"	Hospitals
1.11 Fatigue	Steel	Superstructure		x		TM 5-809-1 AFM 88-3 Ch 1,	Conformance or careful analysis of	

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
1.11 (cont'd)						TM 5-809-10 NAVFAC P-355 AFM 88-3 Ch 13	design Loads in accordance with technical literature	
	Masonry	2.2.3		x		TM 5-809-1 AFM 88-3 Ch 1, TM 5-809-10 NAVFAC P-355 AFM 88-3 Ch 13	Conformance or careful analysis of design loads in with technical literature	
1.12 Accidental/ Special Loads	General	Superstructure	x			ER 1110-345-700 Appendix B Sec 3d	Conformance	PF 40 and above shelter spaces
		Substructure, Superstructure		x		TM 5-1300 NAVFAC P-397 AFM 88-22	Conformance	Calculation procedure
		Substructure, Superstructure	x			ETL 1110-3-328	Conformance	Computer program
	Steel	Superstructure		x		TM 5-809-1/ AFM 88-3 Ch 1, TM-809-10/ NAVFAC P-355/ AFM 88-3 Ch 13	Compliance or careful analysis of design loads in accordance with technical literature	
	Concrete, Cast-in-Place	Substructure: Slab-on-Grade	x			ETL 1110-3-328	As necessary for blast condition	
		Superstructure: Floor Diaphragm/Sheathing/Slab		x		TM 5-1300/ NAVFAC P-397/ AFM 88-22		
	Masonry	Substructure: Basement/ Foundation Walls; Superstructure		x		TM 5-809-1/ AFM 88-3 Ch 1, TM 5-809-10/ NAVFAC P-355/ AFM 88-3 Ch 13	Compliance or careful analysis of design loads in accordance with technical literature	
2.1 Loads & Load Combinations	General	Foundations, Substructure, Superstructure		x		EM 1110-1-2101	Conformance	Loads for working stress
	General	Foundations, Substructure, Superstructure		x		TM 5-809-1 AFM 88-3 Ch 1 (Section 8-1, (6a)	Conformance	

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
2.1 (cont'd)								
	General	Foundations, Substructure, Superstructure		x		TM 5-809-10 NAVFAC P-355 AFM 88-3, Ch 13	Design compliance	Earthquake load
	Steel	Superstructure	x			TM 5-809-1/ AFM 88-3 Ch 1, TM 5-809-10/ NAVFAC P-355/ AFM 88-3	Compliance or careful analysis of design loads in accordance with technical literature	
	Aluminum	Superstructure		x		TM 5-809-1/ AFM 88-3 Ch 1, TM 5-809-10/ NAVFAC P-355/ AFM 88-3	Compliance or careful analysis of design loads in accordance with technical literature	
2.1-2.6	Concrete, Precast/ Prestressed	Superstructure	x			CW-03425	[ACI 318] [PCI-PPC]	
2.1	Concrete, Precast/ Pre-stressed	Superstructure: Floor Diaphragm/Sheathing/Slab, Roof Diaphragm/Sheathing/Slab	x			CEGS-03410	[ACI 318]	
	Masonry	Superstructure: Bearing Walls/Shear Walls		x		TM 5-809-1 AFM 88-3	Conformance, [ANSI A58.1]	
2.2 Strength Properties	Steel	Superstructure: Roof Diaphragm/Sheathing/Slab		x		CE-R-05.2 Sec 1.1	[AISI] minimum section properties	Use 20,000 psi max. working stress
	Concrete, Cast-in-Place	Foundations: Conventional Foundations; Substructure: Basement/Foundation Walls		x		EM 1110-1-2101	f'c = 2,500 psi	For small buildings
		Superstructure		x		EM 1110-1-2101	f'c = 3,000 psi	
		Superstructure	x			EM 1110-1-2101	f'c = 4,000 psi	Where economical in special applications
		Superstructure	x			EM 1110-1-2101	f'c = 5,000 psi	Prestressed members
						EM 1110-1-2101	f'c = 6,000 psi	Prestressed concrete members special cases

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
2.2 (cont'd)		Superstructure		x		CEGS-03300 Section 7.1	3,000 psi	Compressive strength
		Superstructure		x		CEGS-03300 Section 7.1	600 psi	Flexural strength
		Superstructure: Roof Diaphragm/Sheathing/Slab	x			CEGS-03510	Minimum compressive strength by type of form - Table 1 ASTM Tests	Cast-in-place lightweight concrete
	Concrete, Precast/ Pre-stressed	Superstructure: Floor Diaphragm/Sheathing/Slab, Roof Diaphragm/Sheathing Slab	x			CEGS-03410 Section 6, 7.1	Conformance (ACI 318)	
	Masonry	Substructure: Basement/ Foundations Walls; Superstructure: Beams/ Girders/Lintels, Roof Beams/Girders/Purlins/ Rafters Lintels, Bearing Walls/Shear Walls	x			TM 5-809-3	Tables	Tables 2-1 through F-11
2.3 Stiffness/ Vibrations	Steel	Superstructure: Floor Diaphragm/Sheathing/Slab, Roof Diaphragm/ Sheathing/Slab		x		TM 5-809-4 AFM 88-3 Ch 4	≤1/360	Supporting masonry walls, masonry partitions, and/or plastered ceilings
	Steel, Light-Gauge	Superstructure: Roof Diaphragm/Sheathing/Slab	x			CEGS-05311 Part 1, Par 2	(STD1)	
	Concrete, Cast-in-Place	Superstructure: Roof Diaphragm/Sheathing/Slab	x			CEGS-03510	≤1/240 of clear span	Steel forms
	Concrete, Precast/ Prestressed	Superstructure: Roof Diaphragm/Sheathing/Slab	x			CEGS-03414 Tech note F	≤1/180	If appearance not important or where ceiling will be concealed
	Concrete, Precast/ Pre-stressed	Superstructure: Floor Diaphragm/Sheathing/Slab, Roof Diaphragm/Sheathing/ Slab	x			CEGS-03410	Conformance	

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
2.3 (cont'd)								
	Concrete, Composite with Metal Deck	Superstructure: Floor Diaphragm/Sheathing/Slab, Roof Diaphragm/ Sheathing/Slab	x			CEGS-03300 Sec 10.4.1	≤1/240 of clear span	Metal deck form deflection (wet concrete placement procedures)
	Masonry	Superstructure: Bearing Walls/Shear Walls		x		TM 5-809-3	Design aids	
	Timber	Superstructure: Floor Diaphragm/Sheathing/Slab, Roof Diaphragm/Sheathing/ Slab	x			EM 1110-1-2101	≤1/240 of clear under DL + LL	spanPlaces of assembly
		Superstructure: Floor Diaphragm/Sheathing/Slab	x			EM 1110-1-2101	≤1/200 of clear span under DL + LL	
	Cement Plaster	Superstructure: Interior Walls	x			CEGS-09200 Sec 6.1	≤ 0.20" for 2-1/2" steel studs ≤ 0.15" for 3-1/4" steel studs ≤ 0.10" for steel studs > 4" wide	Bending. 6' test sample; 5' clear span; 100 lb center loading
2.4 Strength to Support Loads	Steel	Superstructure	x			EM 1110-1-2101	[AISC] Section 8.8a exceptions if useful occupancy < 5 yr ASTM Tests	
		Superstructure	x			[AEI-DC] Ch 8	[AISC]	Stress allowances
		Superstructure			x	DOD 4270.1-M Ch 6	[AISC]	Stress allowances
		Superstructure: Floor Trusses/Joists, Roof Trusses/ Joists	x			[AEI-DC] Ch 8	[SJI]	Stress allowances
		Superstructure: Floor Trusses/ Joists, Roof Trusses/Joists			x	DOD 4270.1-M Ch 6	[SJI]	Stress allowances
		Superstructure	x			TM 5-809-4	[AISC], compliance	
		Superstructure: Floor Trusses/Joists, Roof Trusses/ Joists	x			TM 5-809-4	[SJI], compliance	

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
2.4 (cont'd)	Steel, Light-Gauge	Superstructure	x			[AEI-DC] Ch 8	[AISI]	Stress allowances
	Steel, Light Gauge	Superstructure	x	x		[AISI] TM 5-809-4	[AISI], compliance	Stress allowances
	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			EM 1110-2-2000 Section 3-2	Conformance	Concrete buildings
		Foundations, Substructure, Superstructure				EM 1110-1-2101	[ACI-318] exceptions if useful occupancy < 5 yr	
		Foundations, Subgstructure, Superstructure	x			EM 1110-2-2000	Conformance	Concrete mixture proportioning (Government)
		Foundations, Substructure, Superstructure	x			[AEI-DC] Ch 8	[ACI-318]	Stress allowances
		Foundations, Subgstructure, Superstructure			x	DOD 4270.1-M Ch 6	[ACI-316;	Stress allowances
	Aluminum	Superstructure	x			EM 1110-1-2101	[ALUM]	
		Superstructure	x			[AEI-DC] Ch 8	[ALUM]	Stress allowances
					x	DOD 4270.1-M Ch 6	[ALUM]	Stress allowances
		Superstructure		x		TM 5-809-4	[ALUM], compliance	
	Masonry	Substructure: Basement/ Foundation Walls; Superstructure: Bearing Walls/Shear Walls		x		TM 5-809-3	Design aids	Appendices A-F
	Masonry	Superstructure: Bearing Walls/Shear Walls	x			TM 5-809-3	Design aids	
		Substructure: Basement/ Foundations Walls, Superstructure	x			[AEI-DC] Ch 8	[ANSI-RM] [BIA] [NCMA]	Stress allowances

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
2.4 (cont'd)								
		Substructure: Basement/ Foundation Walls, Superstructure			x	DOD 4270.1-M Ch 6	[ANSI-RM] [BIA] [NCMA]	Stress allowances
	Timber	Superstructure	x			EM 1110-1-2101	[NLMA] Section 13 exceptions if useful occupancy < 5 yr	
		Superstructure	x			[AEI-DC] Ch8	[INFOPA]	Stress allowances
		Superstructure			x	DOD 4270.1-M Ch 6	[INFOPA]	Stress allowances
2.5 Stable Equilibrium/ Lateral Bracing	Masonry	Superstructure: Bearing Walls/Shear Walls	x			TM 5-809-3	Design aids and formulas	Sec. 4.3, 5.3
3.2 Flame Spread & Potential Heat	General	Superstructure	x			CEGS-07265	ASTM tests	Spray-applied fireproofing
	Concrete, Precast/ Prestressed	Superstructure: Roof Diaphragm/Sheathing/Slab	x			CEGS-03414 Par 6.4	ASTM tests	Cement fiber roof decking
3.3 Fire Resistance & Endurance	General	Superstructure: Special Elements	x			[AEI-DC] Ch 9	4 hr fire resistance rating	Fire walls- warehouse facilities 40,000 sq ft gross area
	General	Superstructure	x			[AEI-DC] Ch 9 Sections 4, 6	[UBC] [NFPA 75]	Fire resistance construction classifications electronic equipment installations
	General	Superstructure: Bearing Walls/Shear Walls Bracing Elements	x			[AEI-DC] Ch 9 Section 6	2 hr FRR or 1 hr, in accordance with [NFPA 101]	Shafts - elevator & stairs
3.6 Protective Devices	General		x			CE-R-15.7 Sec 1	NFPA, 13-1983, Installer experience	Installation

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
5.1 Mechanical Properties	Concrete, Cast-in-Place	Superstructure	x			CEGS-03300 Sec 24	Compliance	Lightweight concrete
	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			CEGS-03300 Sec 6, 8	ASTM tests	
	Concrete, Precast/ Prestressed	Superstructure: Roof Diaphragm/Sheathing/Slab	x			CEGS-03414	ASTM tests	Spans <8 ft
	Reinforcing Steel	Foundations, Substructure, Superstructure	x			CW-03210 Section 4.1	ASTM A 370	
5.2 Wear Resistance	General	Superstructure	x			CEGS-07265	ASTM tests	Spray-applied fireproofing
5.3 Dimensional Stability	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			EM 1110-2-2000 Appendix B	Conformance [ASTM Tests]	Aggrate reactions Appendix C
5.4 Weathering	Concrete, Cast-in-Place	Substructure, Superstructure		x		EM 1110-2-2000 Sec 3-2	Conformance	Air entrainment water/ cement ratio
	Timber	Superstructure: Floor Beams/Girders/Lintels, Floor Trusses/Joists, Roof Beams/Girders/Purlins/ Rafters Lintels, Roof Trusses/Joists, Columns	x			TM 5-809-11	"Minimize decay" "maintain structural Integrity"	Areas subject to typhoons & hurricanes
	Structural Metals (Steel or Aluminum)	Superstructure: Roof Diaphragm/Sheathing/Slab	x			CEGS-13120 Sec 7.3.3	ASTM Tests	Factory finishes
5.5 Rheological Properties	Concrete, Precast/ Prestressed	Superstructure: Floor Diaphragm/Sheathing/Slab, Roof Diaphragm/Sheathing/ Slab	x			CEGS-03410 Section 6	[ACI 318]	
5.6 Environmental Effects	General	Foundations, Substructure, Superstructure		x		TM 5-809-11 AFM 88-3 Ch 14 Section 8-5	Conformance	
	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			EM 1110-2-2000	Conformance	Water/cement ratio

Table A2 (cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
6.1 Structural Planning	General	Foundations, Substructure, Superstructure	x			ETL-1110-3-340 Par 4	UBC construction classification definitions & requirements	DOD 4270.1-M <u>Construction Criteria Manual</u>, 1 June 1978 (revised) governs
	General	Foundations, Substructure, Superstructure	x			ER 1110 -345-700 Appendix B Sec 3c	Conformance	Design objectives & provisions
	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			ER 1110-2-2000 Sec 5-1	Conformance	
	Concrete, Thin Shell	Superstructure: Roof		x		TM 5-809-9 Sec 7e	(ACI SP-4)	Formwork planning for thin-shelled concrete
	Masonry	Superstructure: Bearing Walls/Shear Walls		x		TM 5-809-3 Par 3-4, 3-9	Conformance	Control joint location
6.2 Susceptibility to Structural Analysis	Steel	Foundations, Substructure, Superstructure		x		TM 5-809-4/ AFM 88-3 Ch4 Par 3	"Non-uniqueness"	
	Aluminum	Foundations, Substructure, Superstructure	x			TM 5-809-4/ AFM 88-3 Ch 4 Par 3	"Non-uniqueness"	
6.4 Material Availability	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			EM 1110-2-2000 Sec 2, 5	Compliance	
6.6 Ease of Erection and Coordination	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			EM 1110-2-2000 Sec 3-2, 5-1	Compliance	Concrete mix placeability
6.8 Required Precision & Tolerance/ Quality Control	Steel	Substructure, Superstructure	x			CW-05501 Sec 5.1 —	Allowable variation in overall length of a structural member: $\leq$ 1/32" both ends milled $\leq$ 1/16" without milled ends, and length $\leq$ 30' $\leq$ 1/8" without milled ends and length > 30'	

Table A2 (cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
6.8 (cont'd)								
	Concrete, Cast-in-Place	Foundations	x			MOGS-03302 Sec 7, Tech note A	ACI SP-66	Reinforcement detailing and placement
	Concrete Cast-in-Place	Foundations, Substructure, Superstructure	x			CE-R-03.1 Section 4.2	Entrained air content: 5-7 percent by volume of concrete for exposed exterior concrete	
	Concrete, Cast-in-Place	Substructure Superstructure	x			CEGS-03300 Sec 11.1	[ACI 318]	Reinforcement detailing
	Concrete, Cast-in-Place	Superstructure: Floors	x			CEGS-03300 Sec 11.2	[ACI SP-66]	
	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			CEGS-03300 Sec ?	Compliance	Submittals
	Concrete, Cast-in-Place	Superstructure: Connections/Joints	x			CEGS-03300 Sec 23	Compliance	Base plates bearing plate
	Concrete, Cast-in-Place	Substructure	x			CEGS-03300 Sec ?	[ACI SP-66] [ACI 318]	
	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			EM 1110-2-200	Compliance	Specification tolerances
	Concrete, Cast-in-Place	Superstructure: Floor Diaphragm/Sheathing/Slab, Roof Diaphragm/Sheathing/Slab	x			CEGS-03410 Sec 4	Compliance [ACI 318]	Shop drawing
	Concrete, Cast-in-Place	Superstructure: Roof Diaphragm/Sheathing/Slab	x x			CEGS-03510	Expansion joints 1 1/2" when roof areas < 100' length	Not req'd for vermiculite CCT deck req'd for other LTWT CCT
	Concrete, Cast-in-Place	Superstructure	x			CW-03301 Table 1, Sec 4.3	Within tolerances	

Table A2 (cont'd)

Specific Attribute	Materials	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
6.8 (cont'd)								
	Concrete, Precast/ Prestressed	Superstructure	x			CW-03425 Sec 5 Sec 18	Within tolerances	
	Masonry	Superstructure: Bearing Walls/Walls, Columns	x			CE-R-04.2 Sec 4.12	[ACI SP 66-80]	Reinforcement details
	Reinforcing Steel	Foundations, Substructure, Superstructure	x			CW-03210 Sec 7.3, Sec 7.4	Within tolerances	Spacing, concrete cover, & splicing
	Welded Wire Fabric (WWF) and Other Miscellaneous Reinforcing Material	Superstructure: Floor Diaphragm/Sheathing/Slab	x			CEGS-03300 Technical Note K.	ASTM A497	Wire mesh
7.1 Material Resistance to Deteriora- tion	Concrete, Cast-in- Place	Foundations, Substruc- ture, Superstructure	x			CEGS-03300 Sec 6	ASTM Tests	
	Concrete, Cast-in- Place	Substructure: Slab-on-Grade	x			CEGS-03300 Sec 6	ASTM Tests	
7.1-7.3	Concrete, Precast/ Prestressed	Superstructure	x			CW-03425 Sec 7, 8	ASTM Tests	
7.2 Suscepti- bility to Cracking	Steel	Superstructure	x			MOGS-05121 Sec 7	Compression joints depending on contact bearing shall have a surface roughness not in excess of 500 micro-inches as deter- mined by ANSI B46.1, and ends shall be square within the tolerances for milled ends specified in ASTM A 6	

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
7.2 (cont'd)	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			CW-03150	ASTM Tests contraction and	Expansion, construction joints in concrete
	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			CEGS-03300 Sec 13	Compliance	
	Concrete, Cast-in-Place	Substructure: Slab-on-Grade	x			CEGS-03300 Sec 20	Compliance	
	Masonry	Superstructure: Bearing Walls/Shear Walls			x	TM 5-809-3 Ch 3	Tabular values	
	Required Coatings	Superstructure	x			CEGS-07265	ASTM Tests	Spray-applied fireproofing
7.3 Resistance to Chemical Attack	Steel, Aluminum	Superstructure: Floor Beams/Girders/Joists, Floor Trusses/Joists, Roof Beams/Girders/Purlins/Rafters/Lintels, Roof Trusses/Joists, Bearing Walls/Shear Walls, Bracing Elements, Columns, Tension Members, and Connections/Joints	x			CEGS 13120 Sec 7.3.1 7.3.2 7.3.3	ASTM Tests	Steel covering; aluminum covering
	Concrete, Cast-in-Place	Foundations, Substructure, Superstructure	x			CEGS-03300 Sec 18.4	Compliance	CACl
	Concrete, Cast-in-	Foundations, Substructure, Superstructure	x			EM-1110-2-2000 2-3c, 2-9b	Compliance	Sulfates
	Required coatings	Superstructure	x			CEGS-07265	MIL-STD-810 Method 507.2 Procedure III, modified per CEGS-07265 Par 9.6	Spray Applied Fireproofing
8.2 Span and Size Limits of Components	General	Substructure, Superstructure	x			ER 1110-345-700 Appendix B Sec 3c	Conformance	Design objectives and provisions
9 (General)	Steel	Superstructure: Floor Beams/Girders/Lintels, Floor Trusses/Joists, Roof Beams/Girders/Purlins/Rafters/Lintels, Roof Trusses/Joists, Columns		x		TM 5-809-4/ AFM 88-3 Ch 4 Par 2	"Least cost"	

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
9 (cont'd)								
	Aluminum	Superstructure: Beams/ Girders/Lintels, Floor Trusses/Joists, Roof Beams/ Girders/Purlins/Rafters/ Lintels, Roof Trusses/Joists, Columns	x			TM 5-809-4/ AFM 88-3 Ch 4 Par 2	"Least cost"	
	Masonry	Superstructure: Bearing Walls/Shear Walls	x			TM 5-809-3	Comparison guidelines	
9.1 Material	Steel	Substructure, Superstructure		x		TM 5-809-4/ AFM 88-3 Ch 4	Maintenance cost evaluated	Exposed steel
9.5 Construction Speed	General	Foundations, Substructure, Superstructure	x			ER 1110-345-100 Sec 8, 20 Appendix B, Sec 3c	Compliance	
10.1 Analysis of Connections	Steel	Superstructure: Connections/Joints	x			CEGS-05120 Par 2	[AWS] [AISC-JTS]	
10.2 Connection Detailing and Simplicity	Steel	Superstructure: Connections/Joints	x			CEGS-05120 Par 2	[AISC] [AWS] [AISC-JTS]	
10.2-10.4	Steel	Superstructure: Floor Beams/ Girders/Lintels, Floor Trusses/Joists, Roof Beams/Girder/Purlins/ Rafters/Lintels, Roof Trusses/Joists, Connections/Joints		x		CEGS 13120 Sec 7.2 members	ASTM Tests	Framing and structural
10.3 Joining Materials Interaction	Welded Wire Fabric (WWF) and Other Miscellaneous Reinforcing Material	Superstructure: Bearing Walls/ Shear Walls, Interior Walls		x		CEGS-09200 Section 11	ASTM Tests	Metal lath
10.4 Ability to Receive and Retain Coatings	Concrete, Precast/ Prestressed	Superstructure: Floor Diaphragm/Sheathing/Slab, Roof Diaphragm/ Sheathing/Slab	x			CEGS 03410 Sec 6	Compliance	
11.1 Architectural Design	General	Superstructure	x			ER 1110-345-700 Appendix B Sec 3c	Compliance	

Table A2 (Cont'd)

Specific Attribute	Material	Structural Component	USACE	DA	DOD	Reference	Performance Criteria	Remarks
11 (cont'd)								
11.8 Security System	General	Foundations, Substructure, Superstructure	x			TM 5-853-1 Ch 4	Consideration of security design structural measures	
12.2 Satisfaction of Special Requirements	Steel	Superstructure: Floor Beams/Girders/Lintels, Floor Trusses/Joists, Roof Beams/Girders/Purlins/Rafters/Lintels, Roof Trusses/Joists, Bearing Walls/Shear Walls, Bracing Elements, Columns, Tension Members	x			CEGS-13120 Sec 7.10	Minimum uncoated thickness - 0.048"	Light-gauge steel structural member
	Steel	Superstructure: Roof Diaphragm/Sheathing/Slab	x			CE-R-05.2 Sec 1.2	Deck units fabricated of 22 gauge thick or thicker steel	
	Steel	Superstructure: Roof Diaphragm/Sheathing/Slab	x			CE-R-05.2 Sec 1.3	Minimum gauges for deck installation accessories (which see)	
	Concrete, Precast/Prestressed	Superstructure: Roof Diaphragm/Sheathing/Slab	x			CE-R-03.1 Sec 17.2	See Sec 17.2	Precast hollow core roof plank
	Timber	Superstructure	x			6.6 Section 3	Members marked with American Institute of Timber Construction Quality Mark; AITC Certificate of Conformance indicating conformance with ANSI A190.1	Military family housing
	Masonry Reinforcement	Superstructure: Bearing Walls/Shear Walls, Columns	x			CE-R 04.1 Sec 1.7	ASTM A 615-84a	

APPENDIX B:

ATTRIBUTE WEIGHTING FACTORS

Input was sought from various professionals to determine the weighting factors for the 12 selected attributes. Different types of occupancy were included in the survey. Twenty-four organizations were approached and a total of 12 responses were received; in addition, the authors of this report had input. One response was excluded because it was incomplete. A simple approach was adopted to derive the weighting factors. The value of the rating that constituted the majority of responses for each attribute for a particular type of building occupancy was used to calculate weighting factors. These values are shown in Table B1 and are designated as "R."

Table B1

Values of Maximum Rating (R)

Attribute	Occupancy Type				
No. (N)	Emergency	Institutional	Residential	Commercial	Industrial
1	5	5	5	5	5
2	5	4	4	4	5
3	5	5	5	5	5
4	4	4	5	3, 4 (3.5)	3
5	4	4, 5 (4.5)	3	3, 4 (3.5)	3, 4 (3.5)
6	3	3	4	4	3, 4 (3.5)
7	4	4	3	4	4
8	3, 4 (3.5)	4	4	3	4
9	2	3, 4 (3.5)	4	4	4
10	3, 4 (3.5)	3	3	3	3
11	4	4	3	3, 4 (3.5)	2, 4
12	5	4	3	4	5
R =	48	48	46	46.5	48

The weighting factor was calculated by the formula Y = (1 + R)/R, where Y is the weighting factor for the attributes. These weighting factors are listed in Table B2. Since these values are based on input by professionals who included, for example, structural engineers, architects, and contractors, the weighting factors are believed to be reliable and can be used for future projects involving different types of occupancy.

Following the tables is a sample of the letter sent to professionals in the field. A list of persons contacted is at the end of this appendix.

Table B2

Attribute Weighting Factors (Y)

Attribute No. (N)	Occupancy				
	Emergency	Institutional	Residential	Commercial	Industrial
1	1.104	1.104	1.109	1.107	1.104
2	1.104	1.083	1.087	1.086	1.104
3	1.104	1.104	1.109	1.107	1.104
4	1.083	1.083	1.109	1.075	1.063
5	1.083	1.094	1.065	1.075	1.073
6	1.063	1.063	1.087	1.086	1.073
7	1.083	1.083	1.065	1.086	1.083
8	1.073	1.083	1.087	1.065	1.083
9	1.042	1.073	1.087	1.086	1.083
10	1.073	1.063	1.065	1.065	1.063
11	1.083	1.083	1.065	1.075	1.063
12	1.104	1.083	1.065	1.086	1.104

Sample Letter

October 5, 1987

Dear Sir(s):

A study on the evaluation and forecasting of emerging building technology and structural systems is currently being conducted by the University of Illinois. The study has been sponsored by the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory. The findings of the study will be used by the U.S. Army Corps of Engineers for future military construction projects in the USA.

Please find enclosed a form that enumerates twelve selected structural performance attributes for a typical building structure. Based on your research, observation, experience, and personal judgment, what importance do you think should be attached to each attribute for different types of occupancy? Separate sheets briefly explaining the attributes and giving the scale of rating are attached for your convenience. Please take a few minutes to fill out the form and return it to me at your earliest convenience. The information is required for developing suitable weight factors based on the relative importance or emphasis of each attribute in relation to the overall performance of the structure for the use of a particular structural system for a project. Your help in this regard is greatly appreciated.

Thank you in advance for your time and collaboration.

Sincerely,

Enclosures

Mir M. Ali, Ph.D.
Associate Professor
Structures Division

Enclosure

Explanation of Attributes (no particular order to listing)

Structural Safety:	Relates to performance of the structure and its components at the ultimate load. Ensures safety against collapse under overload conditions.
Structural Serviceability:	Defines the service behavior of the structure, i.e., cracking, excessive deflections, etc. must be avoided, and the structure should have sufficient strength and be in stable equilibrium under service or working loads.
Fire Safety:	The structure must be as safe as possible against fire hazards. In the event of a fire, the flame spread is controlled and strength is maintained for a predicted number of hours by providing adequate fire protection to the structural components.
Habitability:	Defines liveability in the building with regard to water penetration, acoustic environment, thermal characteristics, health, comfort, light, ventilation, and general safety in relation to structural scheme, planning, materials, building form, etc.
Durability:	Includes the ability of the structure and its elements to withstand wear and tear, weathering, creep and shrinkage effects, environmental and chemical effects, corrosion, etc., and maintain dimensional stability during the life of the building.
Constructibility:	Ease of construction of the structural system, ability to surmount site conditions such as transportation, material handling, erection, etc., adaptability to prefabrication and unitized construction, tolerances, simple connection detailing, and similar considerations.
Maintainability:	Includes material resistance to deterioration, corrosion, and chemical attack, repairability, ease of periodic inspection, potential for remodeling, etc.
Architectural Function:	Includes building form and scale relationship, span and size limits of structure components, interior space definition, subdivision, and separation in relation to structural planning, building enclosure, etc.
Economy:	Relates to the cost of material, labor and equipment, construction speed, ease of design modification during construction, maintenance and management costs, etc.

Compatibility:	Includes compatibility of connecting elements, favorable interaction of joining materials, ability of structural members to receive and retain coatings, etc.
System Integration:	The structural system must be integrated with the architectural design and other major building systems, e.g., power and lighting, temperature control, HVAC, plumbing, foundation and possible mechanical and electrical enlargement during the occupancy of the building.
Code Compliance:	Includes review of codes and builder's claim as to code acceptability, and satisfaction of any specific requirements or criteria in conformance with acceptable practice, standards, or reliable publications.

RATING SCALE

Most important	= 5
Very important	= 4
Moderately important	= 3
Somewhat important	= 2
Least important	= 1

Organizations Surveyed

Firm	Person Contacted
1. Skidmore, Owings and Merrill 33 West Monroe Street Chicago, IL 60603	Mr. John Zils Associate Partner
2. Walker Parking Consultants 505 Davis Road Elgin, IL 60123	Dr. Mo Iqbal Chief Structural Engineer
3. Nayyar & Nayyar International 220 S. State Street Suite 1300 Chicago, IL 60604	Mr. Sarv Nayyar President
4. Building Design & Construction 1350 E. Touhy Avenue Des Plaines, IL 60018	Editor
5. Construction Digest 7355 Woodland Drive Indianapolis, IN 46278	Editor

6. Progressive Architecture — Editor
600 Summer Street Box 1361
Stamford, CT 06904

7. Engineering News Record — Editor
1221 Avenue of the Americas
New York, NY 10020

8. American Society of Civil Engineers — Editor
Civil Engineering Magazine
345 E. 47th Street
New York, NY 10017-2398

9. Esca Consultants — Mr. Richard Payne, Vice-President
1606 Willow View Road
Suite 2H
Urbana, IL 61801

10. Wickersheimer Engineers — Mr. David Wickersheimer, President
821 S. Neil Street
Champaign, IL 61820

11. Olsen-Lytle Architects — Mr. Raymond Lytle, Partner
315 S. State Street
Champaign, IL 61820

12. Russell A. Dankert & Associates — Mr. Russell Dankert, President
Architects Planners
303 West Springfield Avenue
Champaign, IL 61820

13. English Brothers Co. — President
807 N. Neil Street
Champaign, IL 61820

14. Abris Ltd. Architects — President
214 W. Main Street
Urbana, IL 61801

15. Turner Construction — Mr. Robert Widing, (312) 558-7600
55 W. Monroe
Chicago, IL 60603

16. HTB, Inc. Architects/Engineers — Keith Hinchey, P.E., Director of Structures, V.P., (405) 525-7451
P.O. Box 1835
Oklahoma City, OK 73101

17. KKBNA — Mr. Shankar Nair, Vice-President, (312) 938-0595
225 N. Michigan Avenue
Chicago, IL 60601

18. DeSimone, Chaplin & Associates
20 Waterside Plaza
New York, NY 10010

Vincent DeSimone
President
(212) 532-2211

19. Bayside Associates
Architects/Engineers
803 Summer Street
Boston, MA 02127

Paul LaRosa
President

20. CBM Engineers
1700 West Loop Street
Suite 830
Houston, TX 77027

Dr. P. V. Balavankar
Executive V.P.
Chief Structural Engineer
(713) 629-1982

21. DeLeuw, Cather & Company
525 W. Monroe Street
Chicago, IL 60606

M. F. Quirk
Office Manager
Structural Department

22. Richard Weingardt Consultants, Inc.
Structural Engineers
1401 17th Street
Suite 400
Denver, CO 80202

John Davis
Associate V.P.
(303) 292-5722

23. Gensler and Associates
Architects
2049 Century Park East
Suite 570
Los Angeles, CA 90067

Mr. Edward Friedrichs
President
(213) 277-7405

24. Alfred Benesch & Company
233 North Michigan Avenue
Suite 1700
Chicago, IL 60601

Mr. Richard Parmelee
Vice-President
Chief Structural Engineer

APPENDIX C:

SAMPLES OF BROCHURES AND PUBLICATIONS COLLECTED

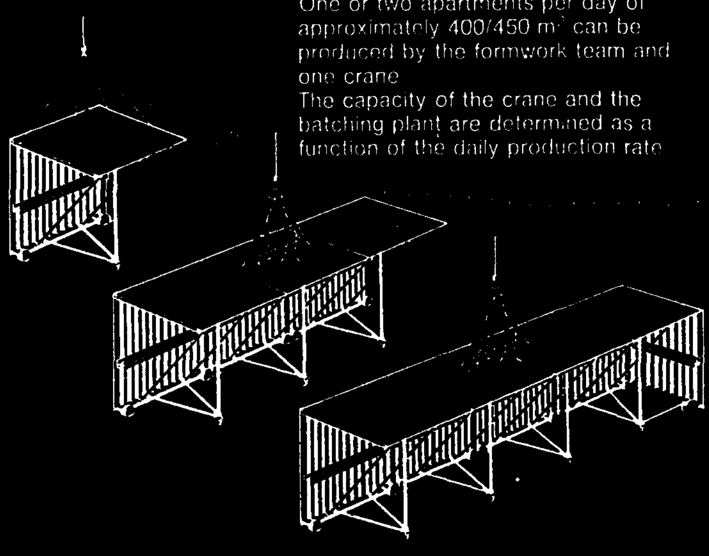
OUTINORD

- *Minimum investments*
  On average the small firm equips itself to produce 20 to 100 apartments per project at a rate of production of 2 to 5 apartments per week. The combination of half tunnels of different spans enables a reduction in the basic amount of equipment purchased.

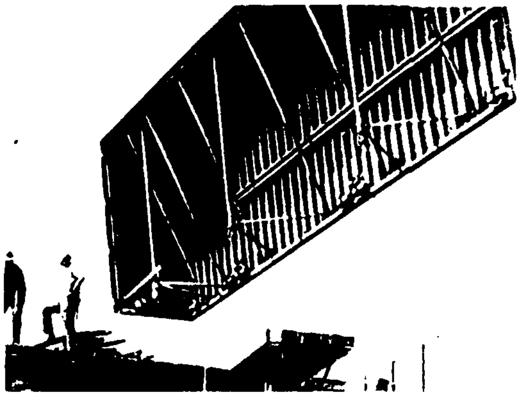
A method which can be adapted to the requirements of individual contractors

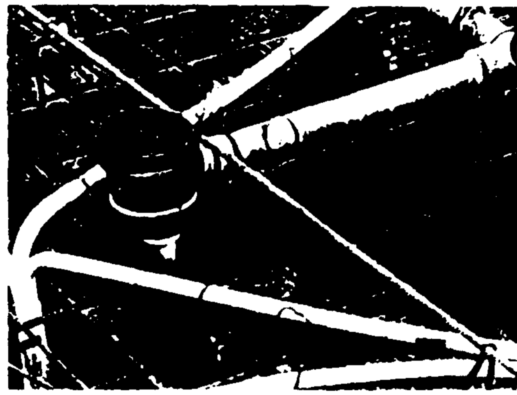
- Rate of Production.
  One or two apartments per day of approximately 400/450 m^2 can be produced by the formwork team and one crane.
  The capacity of the crane and the batching plant are determined as a function of the daily production rate.

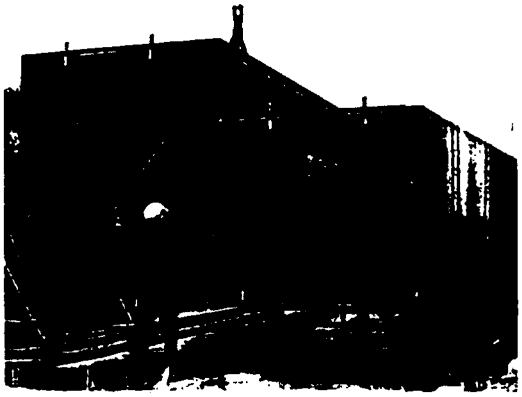
- Adaption and flexibility
  For a new scheme the existing basic equipment can be modified or partly replaced in the following ways:
  - addition of infill panels.
  - recombining existing horizontal panels.
  - Purchase of further horizontal panels.

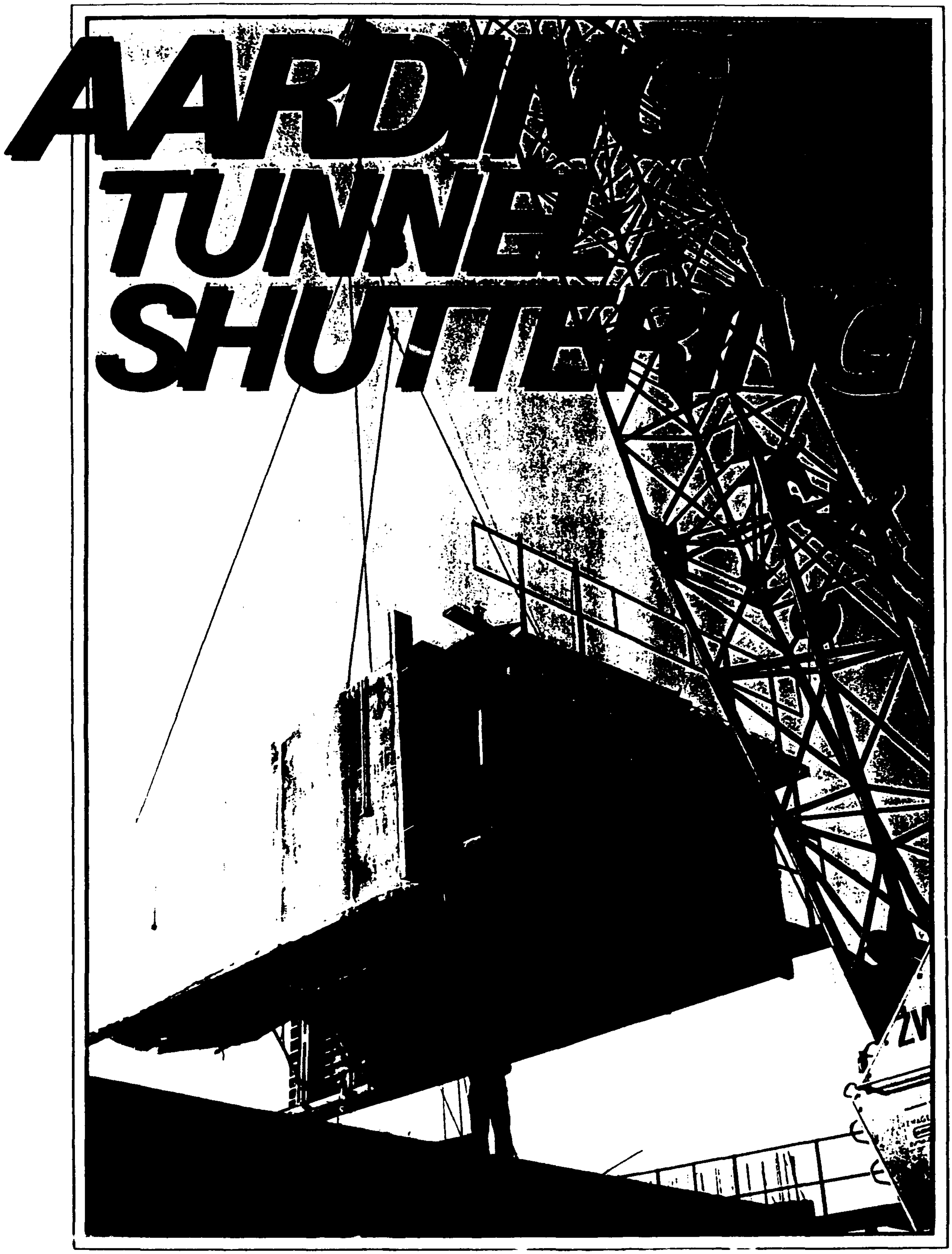


Outinord





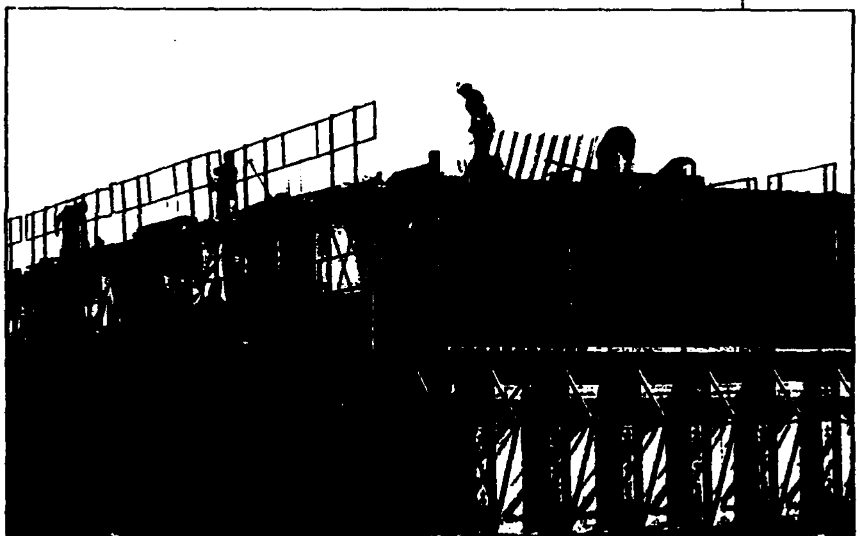


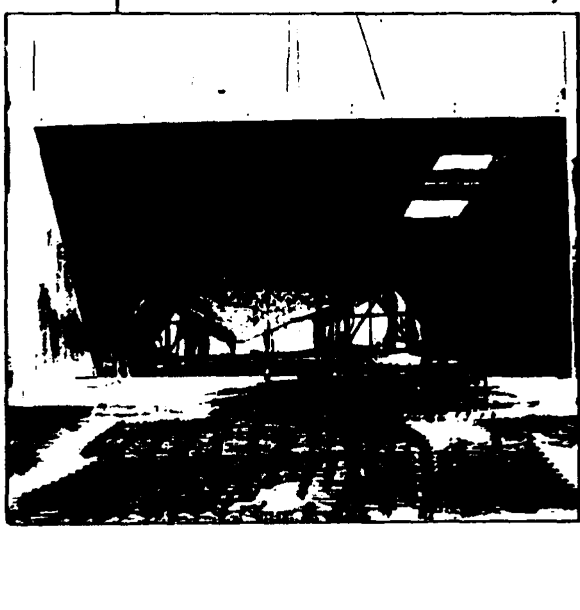

AARDING
TUNNEL
SHUTTERING

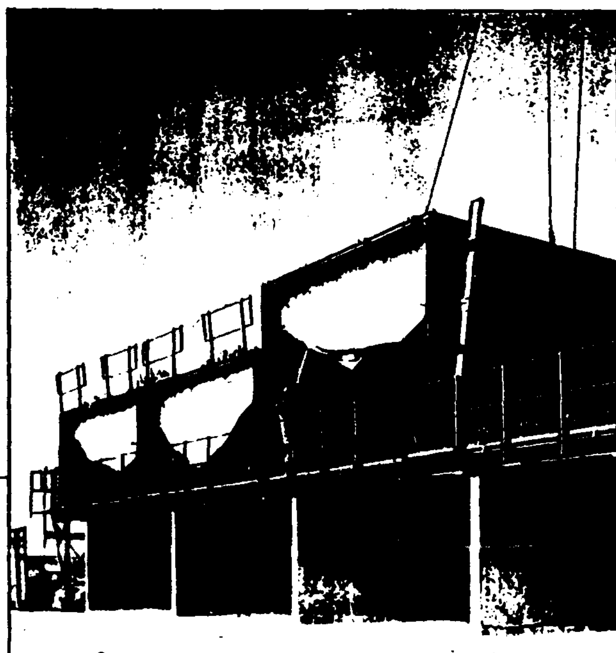
AARDING

SHUTTERING AN INVESTMENT GIVING MORE THAN AMPLE RETURN OF THE COST INVOLVED

,,The proper tool is half the job''. With this slogan in mind AARDING constructs all their shutterings. As a matter of fact the quality supplied by AARDING has its own price. A shuttering of AARDING is not your cheapest buy. But if you also keep in mind the excellent price/quality proportion and the long service life of AARDING shuttering, you will find out soon that in the end you are making the most profitable investment.
It is not surprising, therefore, that AARDING shuttering is used in ever increasing quantities, also on an international scale.
Wherever the highest demands are made as to quality, efficiency and service, the AARDING shuttering is preferred.
An investment more than worth the outlay.







COVINGTON

Save time.
Start with half your wall already built.

Here's the basic module of the building system: a steel wire cage with a core of expanded polystyrene.

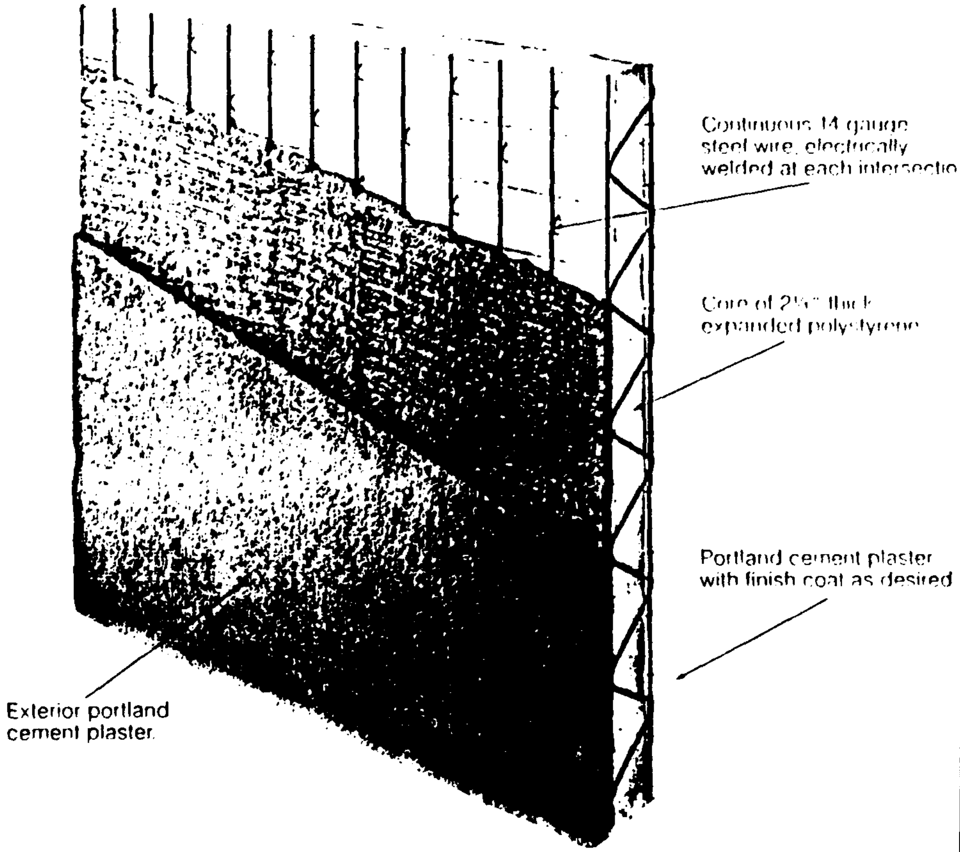
A coat of portland cement plaster is gun or hand applied to the outside and inside. No taping and mudding.

The result is a steel-reinforced concrete wall with excellent structural load bearing qualities.


Tile — Thin-set or float over brown coat


Thin brick and grout—Standard method.


Stucco — Two or three coats, depending on method



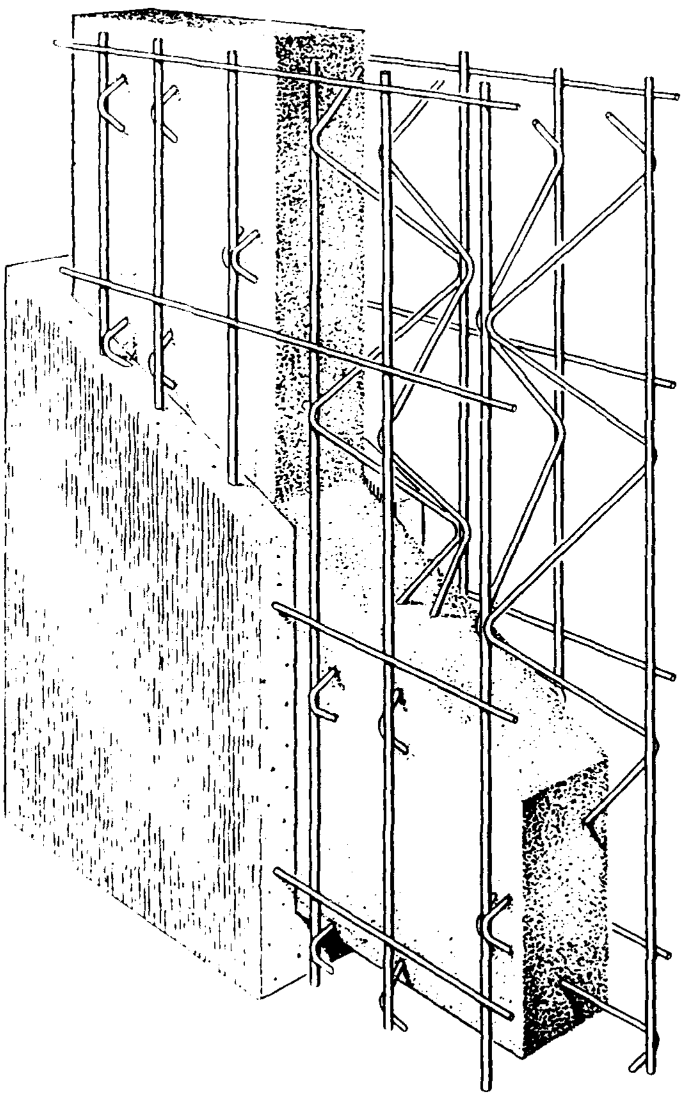
Fire resistant rating: **1 hour:** 1⅛" of portland cement plaster, both sides
2 hours: 1" portland cement, plus ½" lightweight gypsum plaster or ½" lightweight portland cement, both sides


Therml Impac™ Panels used for the roof as well as the walls in low-cost housing — Mexico

TRUSS-TECH

New Building System Provides Structural Strength, Insulation, Versatility!

The construction industry is experiencing a quantum leap in the new variety of building materials, most of which exhibit faster, more economical and versatile ways to meet design needs.



Artist's cut a way illustration shows typical Truss-Tech Building System panel with polyurethane insulation core on which Portland cement, plaster or gunite is applied to complete the advanced technology building system. Heavy wire cage provides strength and rigidity suitable to be used for exterior walls, interior walls, floors, ceilings, all without masonry, wood or metal framing. The system constitutes the entire structure of the building and is fire resistant with insulation and sound qualities that provide contractor with additional advantages in time and cost.

Among those that are now available is the ad[illegible] technology Truss-Tech building system now being [illegible] in a wide range of used in the Southern California area [illegible] available nation wide.

The system provides a structural factory built panel in various sizes and specifications and comes to the jobsite pre-insulated and ready to use completely replacing costly wood or steel framing.

After erection, the panels become a structural unit with Portland cement, gunite or plaster providing a wall of amazing strength completely insulated, rot and termite free, with an outstanding fire resistance.

Interior walls of the Truss-Tech panels can be finished as the design requires with gunite or cement for industrial uses with plaster textures or applied wood paneling for more sophisticated commercial and office uses.

The factory made panels with their polyurethane insulation core can be fabricated or cut into virtually any shape or angle without disturbing their structural integrity.

The Truss-Tech System provides unusual spanning capabilities with lengths 6-to-40 feet and widths of four feet. Also, although they require no framing the panels are used for load bearing walls, floors and roof structures.

The panels provide advantageous energy-saving qualities. In addition, their fire resistant and sound proofing capabilities make Truss-Tech ideal for a wide variety of commercial uses including motels, apartments and senior citizen centers. The systems outstanding insulation factors provide the ultimate material for cold storage warehousing.

The panel's versatility is exhibited through its most recent use in a large custom two-story home in the Sierra Madre area.

The Truss-Tech panels have also been specified as spandrel panels for a large California high rise. Along with this current application, the system is in the planning stage for a multi-story southland hotel.

Regarding maintenance, the building system is durable because of the concrete surfaces that also assures less surface repairs, and repainting. Designed in accordance with the Uniform Building Code 1982 edition and American Concrete Institute Code Requirements for Reinforced Concrete, (ACI 318-71).

The Truss-Tech Building System offices and factory are located in Fontana, California.

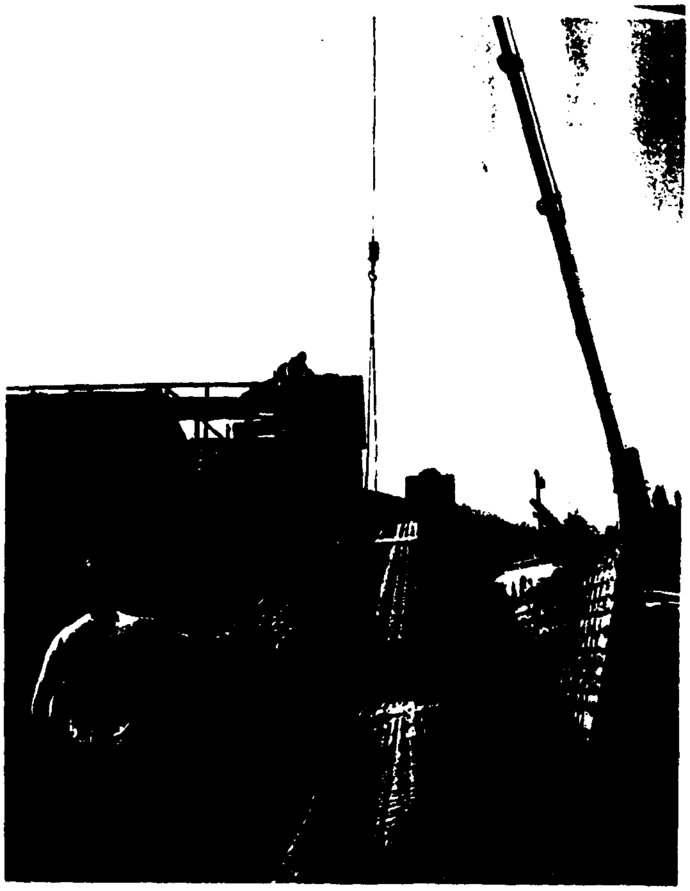


Photo shows Truss-Tech panel, completed with thin set type exterior bricks, ready to be installed at a major high rise office complex. The handsome spandrel panel was put in place in only a few minutes and secured with special pre-installed fasteners.

The spandrel panels will be in the interior in conventional fashion and will provide unusual strength and energy saving qualities as well as meeting a critical construction deadline that is requiring over 400 of the Truss-Tech spandrel panels. ☐

STRICKLAND SYSTEMS

The Concrete InFormer

Published by Strickland Systems, Inc. Where ideas take concrete form.

Now look what our shrinking form has done!

Port Manatee, Palmetto, Florida — There's nothing else like it in the USA, according to Arnold L. Brown, president of POMCO Associates, the Southeastern arm of the Case group of construction companies.

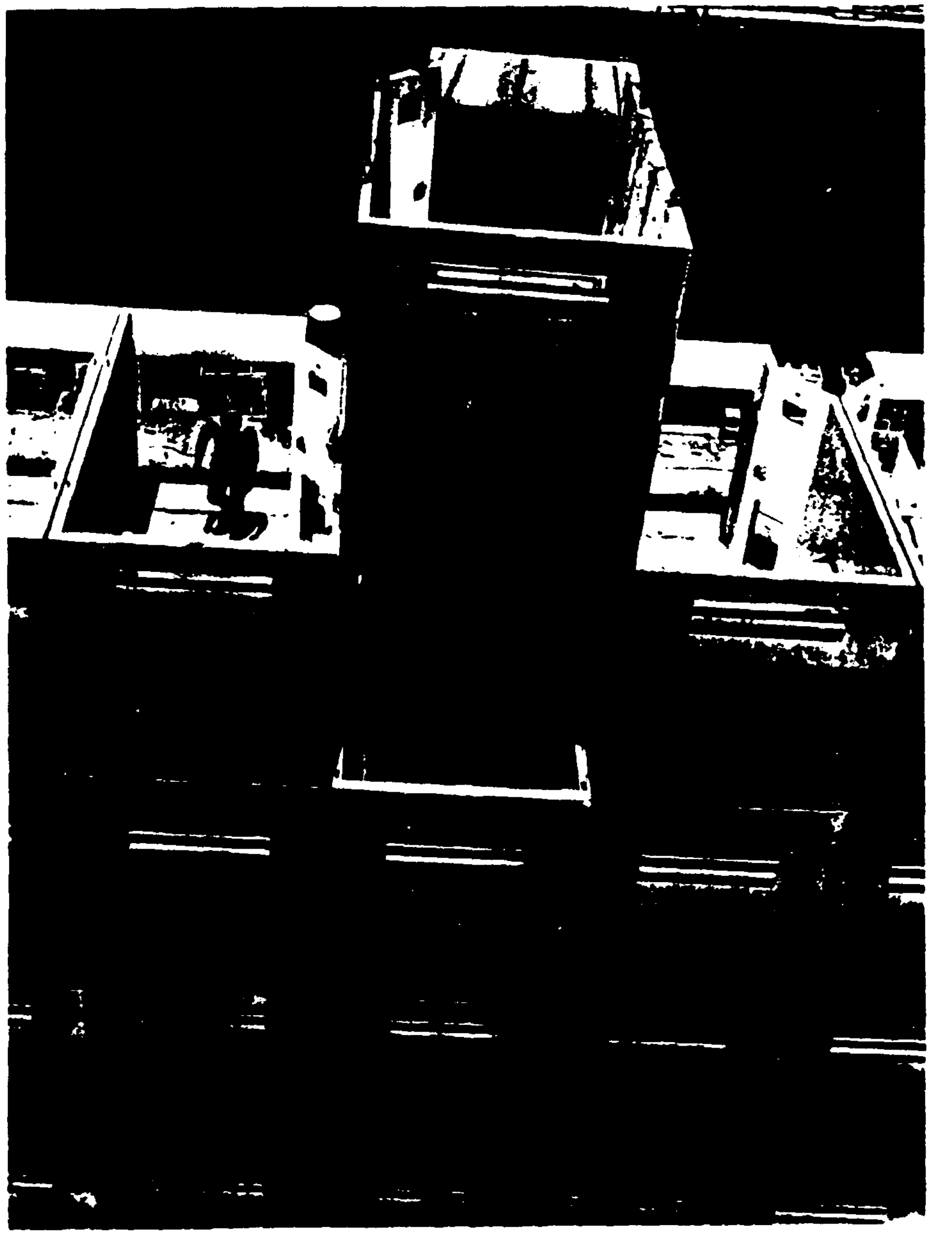
Brown concedes that there are two other jails with modular cells, designed by the same architects, but those cells were cast with conventional "take-apart" forms. Brown, on the other hand, is using forms with the Strickland **InForm** core that **shrinks** itself out of the concrete it has just formed.

And this is the form, the Strickland ***InForm***, *that casts those cells. The* ***InForm*** *can cast all five sides of one or two cells, walls and floor/ceiling, in just one pour. And without a taper in the form or the cell. (See back page.)*

"The modular cells," Brown said, "that Watson & Company came up with are a new and innovative use of precast construction.

"The Strickland forms are a new innovation in modular forms. They are 'state-of-the-art' — much more sophisticated, more innovative than any forms we have seen before.

"Personally, I think this way of casting modular cells is going to be adopted more and more — when the rest of the country sees the quality and the price of the cells. I'm really pleased with the quality of the products."



The cells in this wall are just a few of the 252 prison cells that were cast with Strickland System's shrinking ***InForm***™ *core. The modular cells are being stacked seven high in the new Sarasota County Justice Center, designed by Tampa architects Watson & Company.*

APPENDIX D:

NUMERICAL RESULTS OF EVALUATION

Table D1

Building Technology Rating Sheet

Attribute (N=12)	Engineering Data				
	USACE/Army/DOD Regulations	Codes/Standards	Full-scale Tests	Sample/Model Tests	Field Investigations
1. Structural Safety	6	6	3	5	5
2. Structural Serviceability	6	6	3	3	4
3. Fire Safety	6	6	3	3	4
4. Habitability	5	5	3	4	5
5. Durability	5	5	3	4	5
6. Constructibility	5	5	3	4	5
7. Maintainability	5	4	3	3	4
8. Architectural Function	5	4	3	3	5
9. Economy	5	3	3	3	4
10. Compatibility	6	6	3	3	5
11. System Integration	5	5	3	3	5
12. Code Compliance	6	6	3	3	4

Table D1 (Cont'd)

Empirical Data							
Past Performance	Timeframe of Performance	Observed Changes	Client/User Satisfaction	Future Potential	Score X	Weight Factor, Y	Weighted Score S=(X)(Y)
6	4	5	6	6	52	1.109	57.67
6	4	5	6	6	49	1.087	53.26
6	5	3	5	6	47	1.109	52.12
5	4	3	5	5	44	1.109	48.80
5	5	3	3	5	43	1.065	45.80
5	4	3	5	5	44	1.087	47.83
5	4	5	4	5	42	1.065	44.73
4	4	5	3	5	41	1.087	44.57
4	4	3	3	5	37	1.087	40.22
5	5	3	5	6	47	1.065	50.06
6	5	3	5	6	46	1.065	48.99
6	5	5	5	6	49	1.065	52.19
						Total Score =	586.24*

*Cumulative Score Rating = S = 586. System General Rating = $\frac{S}{N} = 49$

Table D2

Building Technology Ratings Sheet: Composite Panelized System

Attribute (N=12)	Engineering Data				
	USACE/Army/DOD Regulations	Codes/Standards	Full-Scale Tests	Sample/Model Tests	Field Investigations
1. Structural Safety	5	5	3	5	4
2. Structural Serviceability	5	5	3	4	5
3. Fire Safety	5	5	3	6	5
4. Habitability	5	5	3	4	5
5. Durability	6	6	3	4	4
6. Constructibility	5	6	3	3	5
7. Maintainability	4	4	3	3	4
8. Architectural Function	4	5	3	3	5
9. Economy	5	5	3	3	4
10. Compatibility	5	6	3	3	5
11. System Integration	5	5	3	3	5
12. Code Compliance	5	5	3	4	3

Table D2 (Cont'd)

Empirical Data							
Past Performance	**Time Frame of Performance**	**Observed Changes**	**Client/User Satisfaction**	**Future Potential**	**Score X**	**Weight Factor, Y**	**Weighted Score S=(X)(Y)**
6	4	3	6>	6	47	1.109	52.12
5	4	4	3	5	43	1.087	46.74
6	5	3	3	5	46	1.109	51.01
5	4	5	3	3	42	1.109	46.58
5	4	5	3	4	44	1.065	46.86
4	4	3	4	5	42	1.087	46.65
6	4	5	3	5	41	1.065	43.67
4	3	3	3	4	37	1.087	40.22
2	3	3	3	2	33	1.087	35.87
5	3	3	3	4	40	1.065	42.60
5	5	3	3	4	41	1.065	43.67
5	5	3	4	4	41	1.065	43.67

Total Score = 539.66*

*Cumulative Score Rating = S = 540 System General Rating = $\frac{S}{N}$ = 45.

APPENDIX E:

POINTS OF CONTACT

Name & Title of Person	Firm/Organization	Date of Contact System	Structural
Jim Strickland President	Strickland Systems, Inc. Jacksonville, FL (904) 725-8500	9-17-87	Tunnel Form
Jerry Koslowski Vice-President, Marketing	Strickland Systems, Inc. Jacksonville, FL (904) 725-8500	9-17-87	Tunnel Form
Henk de Bruin General Manager	Outinord Universal Co. N. Miami Beach, FL (305) 947-3852	9-18-87	Tunnel Form
Anthony Gallis Product Manager	Patent Scaffolding Co. Fort Lee, NJ 1-800-526-0441	10-7-87	Tunnel Form
Dr. Tseng Chief Structural Engineer	Outinord Universal Co. N. Miami Beach, FL (305) 945-1444	11-24-87	Tunnel Form
Virgil C. Reed President	Synergy Structural Systems Houston, TX (713) 644-0064	11-6-87	Covington/ Truss-Tech Panels
David Stevenson General Manager	Truss-Tech Bldg. Systems Fontana, CA (714) 822-3360	11-24-87 and other occasions	Truss-Tech Panels
Don L. Lloyd President	Covintec International, Inc. Rialto, CA (714) 875-7263	11-24-87 and other occasions	Covington Panels
Ivan Warren Vice President	Aarding Forms, Inc. Canoga Park, CA (818) 883-4990	12-1-87 and other occasions	Tunnel Form
Jacques Swatz Engineering Manager	Aarding Forms, Inc. Canoga Park, CA (818) 883-4990	12-16-87	Tunnel Form
Chandan Das Chief Structural Engineer	Lowy Development Corp. Los Angeles, CA (213) 933-9090	2-25-88	Tunnel Form

Dick Imson Project Manager	Martinez & Wong Architects San Diego, CA (619) 233-4857		Tunnel Form
Rick Mason Contractor	Century Co. Inglewood, CO (303) 694-0017		Tunnel Form
Jacques Aractingi President, Concrete Division	Senseri Construction Chico, CA (916) 891-6444	2-8-88	Tunnel Form
Willie Barry Vice-President	Vern Anthony Gunite Ontario, CA (714) 957-0660	2-18-88	Truss-Tech
Dick Doster General Manager	Outinord Universal Co. N. Miami Beach, FL (302) 947-3852	3-19-88	Tunnel Form
Bob Loer General Manager	Kentucky Fried Chicken Restaurant Castorville, CA (408) 425-1776	2-8-88	Covington
Brian Gerber, P.E. Chiev Evaluator	I.C.B.O. Whittier, CA	1-18-88	Covington
Lawrence W. Hoak, P.E. Vice-President	Vali Associates Anaheim, CA	1-18-88	Covington/ Truss-Tech
John Galbraith Architect	Galbraith Architects Pasadena, CA	2-26-88	Truss-Tech

Attribute Evaluation Worksheet

Building Technology: Tunnel Forming System

Attribute No.: 1 Name of Attribute: Structural Safety

Specific Attribute		Observations/Comments	Rating
1.1	Overloads	Follows ACI code. Designed as monolithic, rigid system (wall-to-slab connection is considered rigid). Calculations are standard.	E
1.2	Collapse Safety/ Ultimate Strength	ACI requirements. No full-scale tests on system or subsystem performed. Results of such test expected to be good.	G
1.3	Formwork/ Temporary Supports	Tunnel forms are metal sheets and are designed adequately; scaffolding is used as required.	E
1.4	Construction Hazards	Not critical.	E
1.5	Changing Structure During Erection and Construction	Accounted for in design and during construction. Pour sequence adopted for concrete placement.	G
1.6	Material Handling & Quality Control	Systematic. Quality control as for any concrete structure.	G
1.7	Strength Against Overloads	Adequate since designed as rigid frame and concrete poured monolithically.	E
1.8	Stability	Follows ACI code. Because of high degree of redundancy, structure is OK. Seismic conditions not as critical since loads are supported on walls rather than columns.	E

Attribute Evaluation Worksheet

Building Technology: Tunnel Forming System

Attribute No.: 1 (cont'd.) Name of Attribute: Structural Safety (cont'd.)

Specific Attribute		Observations/Comments	Rating
1.9	Collapse Mode	OK theoretically. Ensured by design.	G
1.10 1.11	Fracture Fatigue	Unrelated for residential construction.	N
1.12	Accidental/ Special Loads	Unrelated for residential construction. Good performance expected.	N
1.13	Progressive Failure	Monolithic construction; progressive failure is not critical. Needs more information.	F

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
6	6	3	5	5

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Tunnel Forming System

Attribute No.: 2 Name of Attribute: Structural Serviceability

Specific Attribute		Observations/Comments	Rating
2.1	Loads & Load Combinations	Follows ACI loads but can be suited to other specific loading.	E
2.2	Strength Properties	OK. Can be adjusted to specific requirement.	E
2.3	Stiffness/ Vibrations	ACI requirements for stiffness, deflections, etc. are followed. Vibration no problem. Calculations available.	E
2.4	Strength to Support Loads	Calculations available. Special cases may be handled, if required.	G
2.5	Stable Equilibrium/Lateral Bracing	Walls act as shear walls. For low-rise buildings, lateral stability no problem even in seismic zones.	E
2.6	Roof Ponding	No problems encountered.	G

Rating Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale	Model Sample Tests	Field Investigation
6	6	3	3	4

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Tunnel Forming System

Attribute No.: 3 Name of Attribute: Fire Safety

Specific Attribute		Observations/Comments	Rating
3.1	Combustibility	OK as for RC structures.	E
3.2	Flame Spread & Potential Heat		
3.3	Fire Resistance & Endurance		
3.4	Strength Maintenance	Should be OK. In case of fire damage, repair is possible.	G
3.5	Collapse Safety	Should be OK from past experience with concrete structures.	E
3.6	Protective Devices	Not generally required, but possible to integrate fire detectors, extinguishers, etc.	E
3.7	Smoke Propagation/ Toxicity	OK, but needs consideration for a given case. No toxicity present. Smoke propagation depends on structural planning also. Walls act as good fire barriers. Test report on toxicity required for verification.	G

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale	Model/Sample Tests	Field Investigation
6	6	3	3	4

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Tunnel Forming System

Attribute No.: 4 Name of Attribute: Habitability

Specific Attribute		Observations/Comments	Rating
4.1	Water Penetration/ Permeability	OK. Water-repelling admixture may be added to concrete in severely moist or wet surroundings.	G
4.2	Acoustic Environment	For residential construction, impact noises may be uncomfortable unless floor covering is used on floor.	F
4.3	Thermal Properties/ Freeze-Thaw Exposure	As for any reinforced concrete structure.	G
4.4	Health, Comfort, Light, & Ventilation	OK, but because of the low degree of air infiltration, air exchange is required.	F
4.5	General Safety	OK	G

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
5	5	3	4	5

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Tunnel Forming System

Attribute No.: 5 Name of Attribute: Durability

Specific Attribute		Observations/Comments	Rating
5.1	Mechanical Properties	Good against impact, indentation, etc.	E
5.2	Wear Resistance	OK, as for reinforced concrete.	E
5.3	Dimensional Stability	OK. Control joints required as usual. Also, expansion joints required in special cases.	G
5.4	Weathering	OK. May need admixtures in special cases.	G
5.5	Rheological Properties	Could be critical. Needs special consideration to allow for long-term effects in design. For low-rise residential construction, can be controlled.	G
5.6	Environmental Effects	As for any reinforced concrete structures.	G
5.7	Corrosion Resistance		

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
5	5	3	4	5

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Tunnel Forming System

Attribute No.: 6 Name of Attribute: Constructibility

Specific Attribute		Observations/Comments	Rating
6.1	Structural Planning	Planning has to be such that modular construction is possible. This places a limitation on structural planning. For apartments, this is acceptable. For single-family homes, this could be a major drawback.	S
6.2	Susceptibility to Structural Analysis	Very susceptible to analysis. For complex layout, analyses of lateral resisting walls could be somewhat difficult, especially in seismic zones.	G
6.3	Ease of Detailing	Does not seem to be any more difficult than for normal RC construction. Detailing for seismic zones is not complex since slabs are supported on walls rather than columns.	G
6.4	Material Availability	Readily available.	E
6.5	Availability of Skilled Labor & Equipment	Equipment/forms are imported from Europe and are not locally available. Some reusable forms are locally available. Otherwise, a few weeks (about 12 to 16) are needed for the fabricating and shipping of the forms from Europe to the USA. Maintenance of equipment may be a problem. Skilled labor is required.	S

Attribute Evaluation Worksheet

Building Technology: Tunnel Forming System

Attribute No.: 6 (cont'd.) Name of Attribute: Constructibility (cont'd.)

Specific Attribute		Observations/Comments	Rating
6.6	Ease of Erection and Coordination	Normally OK. However, coordination may be a problem if the pace of construction slows or work stalls due to some unforeseen problems, such as equipment breakdown or design modifications. Generally, good scheduling is required.	F
6.7	Adaptability to Prefabrication and Unitized Construction	Quite adaptable.	E
6.8	Required Precision & Tolerance/ Quality Control	Required but OK since tunnel forms are standard. Quality control OK.	G
6.9	Ease of Material Handling	OK	F
6.10	Reuse of Temporary Structures	Tunnel forms are reusable.	E

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds	Full-Scale Tests	Model/SampleTests	Field Investigation
5	5	3	4	5

Specific Attribute Rating: E = Excellent, G = Good, F = Fair, S = Satisfactory, P = Poor, U = Unacceptable, N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Tunnel Forming System

Attribute No.: 7 Name of Attribute: Maintainability

Specific Attribute		Observations/Comments	Rating
7.1	Material Resistance to Deterioration	Similar to reinforced concrete.	G
7.2	Susceptibility to Cracking	Similar to reinforced concrete. For long buildings, expansion joints may be required. For seismic zones, seismic joints may be required for special configuration.	G
7.3	Resistance to Chemical Attack	Similar to concrete. Location should be watched.	G
7.4	Repairability	Cracks could be repaired as for any reinforced concrete structures.	G
7.5	Ease of Periodic Inspection	Inspection of concealed or embedded conduits will need chipping of concrete if there is any problem. Plumbing pipes are installed through a separate shaft and are not embedded in concrete.	S
7.6	Potential for Remodeling	Difficult because walls are permanent. However, drywall/stud partition walls are easy to alter.	S

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
5	4	3	3	4

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding ' Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Tunnel Forming System

Attribute No.: 8 Name of Attribute: Architectural Function

Specific Attribute		Observations/Comments	Rating
8.1	Building Form and Scale	OK. Suitable for row housing, army barracks, apartments, etc. Different forms can be derived.	G
8.2	Span and Size Limits of Components	A span limit on the order of 16 to 18 ft for economical slab thickness. Where longer spans are required, the system could be a problem, although not insurmountable. Use dividing wall where required.	F
8.3	Interior Space Definition, Subdivision & Separation	OK, although not adaptive to future remodeling.	F
8.4	Building Enclosure	Provides a good enclosure against exterior environment.	E

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
5	4	3	3	5

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Tunnel Forming System

Attribute No.: 9 Name of Attribute: Economy

Specific Attribute		Observations/Comments	Rating
9.1	Material	Readily available.	E
9.2	Labor	As for any reinforced concrete construction, although labor has to be skilled and well trained. Once the labor is trained and experienced, the job can be done fast.	F
9.3	Equipment	Quite expensive for small projects. The cost is due to the fact that equipment and forms are imported. Cost is recovered if the forms are used repetitively, i.e., for large projects. Thus, project size is a significant factor.	F
9.4	Design Modifiability During Construction	Could be a problem as for any reinforced concrete construction. The problem is compounded by the modular type of construction if the design amendments are considerable. Partition walls made of stud and drywalls can be easily modified.	F
9.5	Construction Speed	Because of the mechanized and modular system, construction speed is good unless the work stalls for some reason.	E
9.6	Maintenance and Management	OK.	G

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds	Full-Scale Tests	Model/Sample Tests	Field Investigation
5	3	3	3	4

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Tunnel Forming System

Attribute No.: 10 Name of Attribute: Compatibility

Specific Attribute		Observations/Comments	Rating
10.1	Analysis of Connections	Follows ACI code and, hence, the connections can be analyzed if required.	E
10.2	Connection Detailing and Simplicity	Similar to reinforced concrete with special modular characteristics.	E
10.3	Joining Materials Interaction	Compatible with joining materials.	E
10.4	Ability to Receive and Retain Coatings	Similar to reinforced concrete.	E

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
6	6	3	3	5

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Tunnel Forming System

Attribute No.: 11 Name of Attribute: System Integration

Specific Attribute		Observations/Comments	Rating
11.1	Architectural Design	Amenable to architectural functions. Configuration must be modular, however. Any configuration that is not modular is not suited to tunnel forms.	F
11.2	Power & Lighting	OK.	
			G
11.3	Temperature Control		
11.4	HVAC		
11.5	Mechanical/ Electrical Enlargement During Occupancy	Could be a problem in many cases.	F
11.6	Water Supply & Plumbing	OK.	G
11.7	Foundation System	Should be OK in all cases.	E
11.8	Security System	OK	G

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
5	5	3	3	5

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Tunnel Forming System

Attribute No.: 12 Name of Attribute: Code Compliance

Specific Attribute		Observations/Comments	Rating
12.1	Review of Code	Reinforced concrete structure and tunnel forms follow ACI code requirements. Where violations exist in the fields, they must be corrected.	E
12.2	Satisfaction of Specific Requirements	OK in general. Good for seismic zones due to redundancy of the system and presence of shear walls rather than columns. Good against impact loads, blasts, etc.	G

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
6	6	3	3	4

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Composite Panelized System

Attribute No.: 1 Name of Attribute: Structural Safety

Specific Attribute		Observations/Comments	Rating
1.1	Overloads	Follows ACI code although any other code may also be followed if necessary.	G
1.2	Collapse Safety/ Ultimate Strength	ACI requirements met. No test confirmation on full-scale systems or subsystems.	F
1.3	Formwork/ Temporary Supports	Shores, temp. braces for wind loads provided by contractors. Needs to be ensured.	G
1.4	Construction Hazards	Windy situation could be critical when the light panels are being carried.	F
1.5	Changing Structure During Erection and Construction	Wall is often plastered after roof or floor is placed. Covington has a standard manual for erection.	G
1.6	Material Handling & Quality Control	Panels are light and can be carried manually. Covington has quality control (QC) requirements. QC in factory is better than field since conditions are controlled.	E
1.7	Strength Against Overloads	Theoretically OK; practically, not known under overload conditions.	F
1.8	Stability	Follows ACI code. No problems encountered. Full-Scale tests not done. Performs well during earthquakes due to low mass. Axial load tests OK on panels.	G

Attribute Evaluation Worksheet

Building Technology: Composite Panelized System

Attribute No.: 1 (cont'd.) Name of Attribute: Structural Safety (cont'd.)

Specific Attribute		Observations/Comments	Rating
1.9	Collapse Mode	OK theoretically. Practically, not known under overload conditions.	F
1.10	Fracture	Unrelated for residential construction.	N
1.11	Fatigue	Unrelated for residential construction. Not known for seismic conditions.	N
1.12	Accidental/ Special Loads	Unrelated.	N
1.13	Progressive Failure	Progressive failure is not critical since walls are monolithic and so are slabs. Needs testing and more information.	F

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
5	5	3	5	4

Specific Attribute Rating: E = Excellent, G = Good, F = Fair, S = Satisfactory, P = Poor, U = Unacceptable, N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0.

Attribute Evaluation Worksheet

Building Technology: Composite Panelized System

Attribute No.: 2 Name of Attribute: Structural Serviceability

Specific Attribute		Observations/Comments	Rating
2.1	Loads & Load Combinations	Follows standard ACI loads but can be suited to other specific loading.	E
2.2	Strength Properties	OK and can be adjusted to specific needs.	E
2.3	Stiffness/ Vibrations	Calculations available. No vibration test done. No complaints. Deflection tests on panels done.	F
2.4	Strength to Support Loads	Calculations available. Other cases may be accommodated by modifying design.	G
2.5	Stable Equilibrium/Lateral Bracing	Walls act as shear walls. Calculations available.	G
2.6	Roof Ponding	OK. No problems encountered.	G

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model Sample Tests	Field Investigation
5	5	3	4	5

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Evaluation Worksheet

Building Technology: Composite Panelized System

Attribute No.: 3 Name of Attribute: Fire Safety

Specific Attribute		Observations/Comments	Rating
3.1	Combustibility	OK tested following ASTM E119 standards by Warrock Hersey Int'l, Inc.	G
3.2	Flame Spread & Potential Heat	One or two-hour flame-spread rating, depending on thickness of plaster.	G
3.3	Fire Resistance & Endurance	OK. ASTM E119 std. requirements are met.	G
3.4	Strength Maintenance	Difficult to evaluate without a full-scale test.	S
3.5	Collapse Safety	Appears reasonable. Seems to be better than wood frame construction. Verified by field observation at a fire-damaged house at Rialto, CA.	E
3.6	Protective Devices	Possible to integrate.	G
3.7	Smoke Propagation Toxicity	OK, but difficult to confirm.	F

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
5	5	3	6	5

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Composite Panelized System

Attribute No.: 4 Name of Attribute: Habitability

Specific Attribute		Observations/Comments	Rating
4.1	Water Penetration Permeability	Water penetration through joints not a problem because the plaster is monolithic. Also, walls are impermeable. No signs of problems during field visit.	E
4.2	Acoustic Environment	No test results available. Analysis may be done for a particular case. Because of the sandwich-type panels, acoustics are good for airborne noise, but not for noise caused by impact, as in floors. Testing is desirable.	F
4.3	Thermal Properties/ Freeze-Thaw Exposure	Freeze-thaw cycle test showed no signs of cracking, spalling, peeling, etching or scaling. Some heat loss expected, though.	G
4.4	Health, Comfort, Light, & Ventilation	OK, but because of the low degree of air infiltration, air change is desired.	F
4.5	General Safety	OK.	G

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
5	5	3	4	5

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Composite Panelized System

Attribute No.: 5 Name of Attribute: Durability

Specific Attribute	Observations/Comments	Rating
5.1 Mechanical Properties	Good against indentation, impacts, etc.	G
5.2 Wear Resistance	OK.	G
5.3 Dimensional Stability	OK. Control joints required as usual.	G
5.4 Weathering	Seems OK. Various admixtures may be added to plaster for special cases.	G
5.5 Rheological Properties	Not any more critical than concrete or masonry, but no relevant data available.	N
5.6 Environmental Effects	As good as concrete. Needs further tests/observations.	F
5.7 Corrosion Resistance	No rust staining found by tests (ASTM B 117) and during field observations.	E

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
6	6	3	4	4

Specific Attribute Rating: E = Excellent, S = Satisfactory, N = Unrelated/Unknown, G = Good, P = Poor, F = Fair, U = Unacceptable

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Composite Panelized System

Attribute No.: 6 Name of Attribute: Constructibility

Specific Attribute		Observations/Comments	Rating
6.1	Structural Planning	System is adaptable to different types of planning for residential construction.	E
6.2	Susceptibility to Structural Analysis	Can be analyzed as shown by calculations. Many assumptions and idealizations involved.	G
6.3	Ease of Detailing	Quite satisfactory as is apparent from sketches submitted. No building under construction could be inspected to confirm this.	G
6.4	Material Availability	All materials are available in the USA.	E
6.5	Availability of Skilled Labor & Equipment	Available locally. No special skill required for labor. Training required since the mode of construction is non-traditional.	G
6.6	Ease of Erection and Coordination	Quite satsifactory. Cutting wires could be difficult in the field, particularly for Truss-Tech Panels.	F
6.7	Adaptability to Prefabrication and Unitized Construction	Quite adaptable. Has been done in some cases.	E

Attribute Evaluation Worksheet

Building Technology: Composite Panelized System

Attribute No.: 6 (cont'd.) Name of Attribute: Constructibility (cont'd.)

Specific Attribute	Observations/Comments	Rating
6.8 Required Precision & Tolerance/ Quality Control	No additional precision required compared to normal construction. Quality control OK.	G
6.9 Ease of Material Handling	Quite easy to handle materials.	E
6.10 Reuse of Temporary Structures	OK. Fewer temporary structures required compared to concrete, i.e., no formwork required for walls and slabs, and hence less reuse necessary. Temporary braces can be reused.	E

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
5	6	3	3	5

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Composite Panelized System

Attribute No.: 7 Name of Attribute: Maintainability

Specific Attribute		Observations/Comments	Rating
7.1	Material Resistance to Deterioration	Similar to reinforced concrete. No deterioration found in buildings visited.	G
7.2	Susceptibility to Cracking	Similar to reinforced concrete. Control joints may be required for long walls.	G
7.3	Resistance to Chemical Attack	Similar to concrete. Should be further investigated.	F
7.4	Repairability	Can be easily repaired, if required. Plaster is tough enough against impact because of the reinforcing.	G
7.5	Ease of Periodic Inspection	OK. in general. Panels need to be broken for repairing or inspection of concealed pipelines.	F
7.6	Potential for Remodeling	Wall panels used as partition walls could be problematic.	P

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
4	4	3	3	4

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Evaluation Worksheet

Building Technology: Composite Panelized System

Attribute No.: 8 Name of Attribute: Architectural Function

Specific Attribute No.		Observations/Comments	Rating
8.1	Building Form and Scale	OK. Suitable for small buildings, particularly small homes.	G
8.2	Span and Size Limits of Components	Span limit exists. Similarly, wall thickness has limitation. Limitation is more critical for Covington. Truss-Tech offers more variety and flexibility. Span/size limits for low-rise buildings are often within acceptable range.	F
8.3	Interior Space Definition, Subdivision & Separation	OK, although not adaptive to future changes.	F
8.4	Building Enclosure	Provides a good enclosure--almost as good as for reinforced concrete. Esthetics could be improved by variations in color, texture, brick/stone veneers, etc.	E

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
4	5	3	3	5

Specific Attribute Rating: E = Excellent, G = Good, F = Fair, S = Satisfactory, P = Poor, U = Unacceptable, N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Composite Panelized System

Attribute No.: 9 Name of Attribute: Economy

Specific Attribute No.		Observations/Comments	Rating
9.1	Material	Plaster could be expensive in some areas. Spray is required and is rather labor intensive. Needs more market acceptance.	F
9.2	Labor	Not much skilled labor is required.	G
9.3	Equipment	OK. At most, a forklift is required during construction.	G
9.4	Design Modifiability During Construction	OK with exceptions. Top and bottom reinforcements are same in slabs and hence, unlike RC, additional supports may be added.	G
9.5	Construction Speed	Can be built fast.	G
9.6	Maintenance and Management	OK.	G

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model Sample Tests	Field Investigation
5	5	3	3	4

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Composite Panelized System

Attribute No.: 10 Name of Attribute: Compatibility

Specific Attribute No.		Observations/Comments	Rating
10.1	Analysis of Connections	Can be done as for any other connections in a different system. No unusual connection present. Test results not available for connections.	G
10.2	Connection Detailing and Simplicity	A large number of sketches have been developed by Covington and Truss-Tech. Connection details seem simple and acceptable.	G
10.3	Joining Materials Interaction	Slab panels cannot be used on wood-frame walls (code prohibits this). Compatible with all joining materials.	G
10.4	Ability to Receive and Retain Coatings	Can receive and retain coatings. Susceptible to good finish. Can hold tiles and brick or stone veneers.	G

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model Sample Tests	Field Investigation
5	6	3	3	5

Specific Attribute Rating: E = Excellent G = Good F = Fair S = Satisfactory P = Poor U = Unacceptable N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Composite Panelized System

Attribute No.: 11 Name of Attribute: System Integration

Specific Attribute		Observations/Comments	Rating
11.1	Architectural Design	Amenable to architectural functions. Allows freedom in architectural layout.	E
11.2	Power & Lighting	OK.	G
11.3	Temperature Control		
11.4	HVAC	OK. No problem encountered.	G
11.5	Mechanical/ Electrical Enlargement During Occupancy	Could pose a problem in some cases.	F
11.6	Water Supply & Plumbing	OK. However, vertical pipe run could be difficult for Truss-Tech Panels.	F
11.7	Foundation System	Adequate details have been developed.	G
11.8	Security System	OK.	G

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-Scale Tests	Model/Sample Tests	Field Investigation
5	5	3	3	5

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

Attribute Evaluation Worksheet

Building Technology: Composite Panelized System

Attribute No.: 12 Name of Attribute: Code Compliance

Specific Attribute No.		Observations/Comments	Rating
12.1	Review of Code	Requirements of UBC (ICBO), ACI, ASTM met in most cases. NRB approval exists.	G
12.2	Satisfaction of Specific Requirements	Although not explicitly required by code, more full-scale tests are required. Seismic requirements are generally met. Better evidence of performance in hurricane zones required. Also, blast resistance appears to be good but needs verification.	F

Rating of Attribute for "Engineering Data":

USACE/Army/DOD Regulations	Codes/Stds.	Full-scale Tests	Model/Sample Tests	Field Investigation
5	5	3	4	3

Specific Attribute Rating: E = Excellent G = Good F = Fair
S = Satisfactory P = Poor U = Unacceptable
N = Unrelated/Unknown

Attribute Rating Scale: Outstanding = 6 Unsuitable = 0

USACERL DISTRIBUTION

Chief of Engineers
ATTN: CEHEC-IM-LH (2)
ATTN: CEHEC-IM-LP (2)
ATTN: CECC-P
ATTN: CECW
ATTN: CECW-O
ATTN: CECW-P
ATTN: CECW-RR
ATTN: CEMP
ATTN: CEMP-C
ATTN: CEMP-E
ATTN: CEMP-EA
ATTN: CERD
ATTN: CERD-L
ATTN: CERD-C
ATTN: CERD-M
ATTN: CERM
ATTN: DAEN-ZCE
ATTN: DAEN-ZCI
ATTN: DAEN-ZCM
ATTN: DAEN-ZCZ

CEHSC
ATTN: CEHSC-ZC 22060
ATTN: DET III 79906
ATTN: CEHSC-F 22060
ATTN: CEHSC-TT-F 22060

US Army Engineer Districts
ATTN: Library (40)

US Army Engr Divisions
ATTN: Library (14)

US Army Europe
ODCS/Engineer 09403
ATTN: AEAEN-FE
ATTN: AEAEN-ODCS
V Corps
ATTN: DEH (11)
VII Corps
ATTN: DEH (16)
21st Support Command
ATTN: DEH (12)
USA Berlin
ATTN: DEH (9)
Allied Command Europe (ACE)
ATTN: ACSGEB 09011
ATTN: SHIHB/Engineer 09055
ATTN: AEUES 09168
USASETAF
ATTN: AESE-EN-D 09019

8th USA, Korea (19)

ROK/US Combined Forces Command 96301
ATTN: EUSA-HHC-CFC/Engr

Ft. Leonard Wood, MO 65473
ATTN: Canadian Liaison Officer
ATTN: German Liaison Staff
ATTN: British Liaison Officer (2)
ATTN: French Liaison Officer

USA Japan (USARJ)
ATTN: DCSEN 96343
ATTN: Facilities Engineer 96343
ATTN: DEH-Okinawa 96331

Area Engineer, AEDC-Area Office
Arnold Air Force Station, TN 37389

416th Engineer Command 60623
ATTN: Facilities Engineer

US Military Academy 10996
ATTN: Facilities Engineer
ATTN: Dept of Geography & Computer Sciences
ATTN: MAEN-A

AMC - Dir., Inst., & Svcs.
ATTN: DEH (22)

DLA ATTN: DLA-WI 22304

DNA ATTN: NADS 20305

FORSCOM (28)
FORSCOM Engineer, ATTN: Spt Det. 15071
ATTN: DEH

HSC
Ft. Sam Houston AMC 78234
ATTN: HSLO-F
Fitzsimons AMC 80045
ATTN: HSHG-DEH
Walter Reed AMC 20307
ATTN: Facilities Engineer

INSCOM - Ch, Instl. Div.
Arlington Hall Station 22212
ATTN: Engr & Hsg Div
Vint Hill Farms Station 22186
ATTN: IAV-DEH

USA AMCCOM 61299
ATTN: AMSMC-RI
ATTN: AMSMC-IS

Military Dist of Washington
ATTN: DEH
Cameron Station (3) 22314
Fort Lesley J. McNair 20319
Fort Myer 22211

Military Traffic Mgmt Command
Falls Church 20315
Oakland Army Base 94626
Bayonne 07002
Sunny Point MOT 28461

NARADCOM, ATTN: DRDNA-F 01760

TARCOM, Fac. Div. 48090

TRADOC (19)
HQ, TRADOC, ATTN: ATEN-DEH 23651
ATTN: DEH

TSARCOM, ATTN: STSAS-F 63120

USAIS
Fort Huachuca 85613
ATTN: Facilities Engineer (3)
Fort Ritchie 21719

WESTCOM
Fort Shafter 96858
ATTN: DEH
ATTN: APEN-A

SHAPE 09055
ATTN: Survivability Sect. CCB-OPS
ATTN: Infrastructure Branch, LANDA

HQ USEUCOM 09128
ATTN: ECJ 4/7-LOE

Fort Belvoir, VA
ATTN: Australian Liaison Officer 22060
ATTN: Water Resource Center 22060
ATTN: Engr Studies Center 22060
ATTN: Engr Topographic Lab 22060
ATTN: ATZA-TE-SW 22060
ATTN: CECC-R 22060

CECRL, ATTN: Library 03755

CEWES, ATTN: Library 39180

HQ, XVIII Airborne Corps and
Ft. Bragg 28307
ATTN: AFZA-DEH-EE

Chanute AFB, IL 61868
3345 CES/DE, Stop 27

AMMRC 02172
ATTN: DRXMR-AF
ATTN: DRXMR-WE

Norton AFB, CA 92409
ATTN: AFRCE-MX/DE

Tyndall AFB, FL 32403
AFESC/Engineering & Service Lab

NAVFAC
ATTN: Division Offices (11)
ATTN: Facilities Engr Cmd (9)
ATTN: Naval Public Works Center (9)
ATTN: Naval Civil Engr Lab (3)
ATTN: Naval Constr Battalion Ctr 93043

Engineering Societies Library
New York, NY 10017

National Guard Bureau 20310
Installation Division

US Government Printing Office 20401
Receiving/Depository Section (2)

US Army Env. Hygiene Agency
ATTN: HSHB-ME 21010

Nat'l Institute of Standards & Tech 20899

Defense Technical Info. Center 22304
ATTN: DTIC-FAB (2)

320
11/90

Habitability Team Distribution

US Army Engineer Districts
ATTN: Chief, Engineer Division
New York 10278
Buffalo 14207
Pittsburgh 15222
Philadelphia 19106
Baltimore 21203
Norfolk 23510
Huntington 25721
Wilmington 28401
Charleston 29402
Savannah 31402
Jacksonville 32232
Mobile 36652
Nashville 37202
Memphis 38103
Vicksburg 39180
Louisville 40201
Detroit 48231
St. Paul 55101
Chicago 60606
St. Louis 63101
Kansas City 64106
Omaha 68102
New Orleans 70160
Fort Worth 76102
Galveston 77553
Albuquerque 87103
Los Angeles 90053
San Francisco 94105
Sacramento 95814
Japan 96343
Portland 97208
Seattle 98124
Walla Walla 99362
Alaska 99506
Tulsa 74121
ATTN: SWTED
Far East 96301
ATTN: POFED-L

US Army Engineer Division
ATTN: Chief, Engineering Division
New England 02154
Europe 09757
North Atlantic 10007
South Atlantic 30303
Huntsville 35807
Mississippi Valley 39180
Ohio River 45201
Missouri River 68101
Southwestern 75242
South Pacific 94111
Pacific Ocean 96858
North Pacific 97208

Tyndall AFB, FL 32403
ATTN: RD

Dir, Bldg Tech & Safety Div 20410

Director, Center for Bldg Tech 20234

Nat'l Institute of Bldg Sciences 20005

Public Building Service 20405